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(71) Applicant: SHARP KABUSHIKI KAISHA
Osaka 545 (JP)

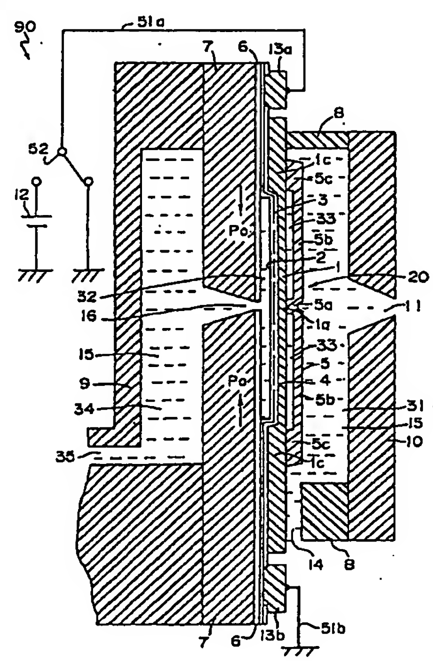
(72) Inventors:
- Hirata, Susumu
Ikoma-gun, Nara-ken (JP)
- Matoba, Hirotsugu
Sakurai-shi, Nara-ken (JP)
- Inui, Tetsuya
Nara-ken (JP)
- Ishii, Yorishige
Yamatotakada-shi, Nara-ken (JP)
- Abe, Shingo
Tenri-shi, Nara-ken (JP)
- Kimura, Masaharu
Daitou-shi, Osaka-fu (JP)
- Horinaka, Hajime
Kashiba-shi, Nara-ken (JP)
- Onda, Hiroshi
Yamatokooriyama-shi, Nara-ken (JP)

(74) Representative: TER MEER - MÜLLER - STEINMEISTER & PARTNER
Mauerkircherstrasse 45
81679 München (DE)

(54) Ink jet head for high speed printing and method for it's fabrication

(57) The invention provides an ink jet head which exhibits a good response characteristic through heating and fast cooling enough to implement high-speed printing. A nozzle plate (10) having a nozzle orifice (11), and a substrate (7) constitute part of a peripheral wall of an ink chamber (31). A pressure generating member (20) is provided in the ink chamber (31). The pressure generating member (20) has a buckling member (1), a heater layer (3), and a diaphragm (5). The buckling member (1) is formed into a generally plate shape and its peripheral portion is attached to the substrate (7). The buckling member (1) can be switched between a no-displacement state in which it undergoes substantially no thermal stress, and a buckled state in which it is thermally expanded and buckled. The heater layer (3) is provided along a surface of the buckling member (1) on the substrate (7) side. The diaphragm (5) is composed of a generally plate-shaped flexible material and provided along a surface of the buckling member (1) on the nozzle plate (10) side in such a state that at least its peripheral portion (5c) is attached to a peripheral portion (1c) of the buckling member (1).

Fig. 1



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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an ink jet head that performs recording by jetting and flying ink liquid. The present invention also relates to a method for fabricating the ink jet head.

2. Description of the Prior Art

There have been commercially available ink jet heads based on various droplet discharge principles. In one type of ink jet head, for example, ink is discharged through a nozzle hole of an ink chamber by mechanical deformation of a piezoelectric device (piezoelectric device system). In another type, ink is boiled by heating with a header so that bubbles are generated, and the ink is discharged through a nozzle by pressure changes due to the bubble generation (bubble jet system).

Under such circumstances, there has recently been proposed an ink jet head 510 using a pressure generating member 501 that will generate heat and deform by electrical energization, as shown in Fig. 32 (Japanese Patent Publication No. HEI 2-30543). In this ink jet head 510, a pair of electrodes 513b, 513b are provided at both ends of a nozzle plate 511 having a nozzle opening 511a, with insulating films 513a, 513a interposed between the electrodes and the nozzle plate. Also, the plate-shaped pressure generating member 501 is stretched between these electrodes 513b, 513b so as to connect them with each other, and a cover member 515 is provided so as to accommodate these components therein. In operation, ink 80 is fed from a preliminary ink chamber 532 so that a clearance 530 between the nozzle plate 511 and the pressure generating member 501 as well as a rear side 531 of the pressure generating member 501 are filled with the ink 80. Then, during a heating period, the pressure generating member 501 is energized through the electrodes 513b, 513b to generate heat. Through this heat generation, the pressure generating member 501 undergoes a thermal stress due to its thermal expansion coefficient so that its center portion is displaced in a direction perpendicular to the plate plane. As a result, the pressure generating member 501 causes a pressure to be generated in the ink chamber, whereby the ink 80 is discharged in the form of particles through the nozzle opening 511a. When a cooling period is entered after completion of the heating period, the energization is stopped and the pressure generating member 501 is cooled to restore to the original configuration (position). By such heating period and cooling period being repeated, the displacement and restoration of the pressure generating member 501 are repeated.

However, the aforementioned ink jet head 510 has been given almost no technical idea with respect to heat radiation of the pressure generating member 501, such that particularly on the preliminary ink chamber 532 side of the pressure generating member 501, the ink 80 of relatively low thermal conductivity is present alone. This accounts for a low cooling rate of the pressure generating member 501 in operation, so that the response characteristic is too poor to attain high speed printing, as a problem. Also, the nozzle plate side clearance 530 and the rear side space 531 of the pressure generating member 501 are communicating directly with each other. Therefore, the ink present in the clearance 530 between the nozzle plate 511 and the pressure generating member 501 tends to go around to the rear side space 531 of the pressure generating member when it undergoes a pressure on the nozzle plate 511 side by the pressure generating member 501 in operation. This leads to another problem that the discharge force and discharge velocity of ink are low.

SUMMARY OF THE INVENTION

An object of the present invention is therefore to provide an ink jet head having a good response characteristic through heating and fast cooling so that it can perform high speed printing. Another object of the present invention is to provide an ink jet head which can prevent ink present in clearance between a nozzle plate and a pressure generating member from going around to a rear side of the pressure generating member, whereby the discharge force and discharge velocity of ink can be increased. Yet another object of the present invention is to provide an ink jet head which is small in size and long in life. A further object of the present invention is to provide a method for fabricating the aforementioned ink jet heads into small size and with simplicity.

In order to achieve the aforementioned object, there is provided an ink jet head which comprises: an ink chamber including as part of its peripheral wall a nozzle plate having a nozzle opening, and a substrate opposed to the nozzle plate; and a pressure generating member provided in the ink chamber and opposed to the nozzle plate, wherein the pressure generating member is deformed to generate a pressure within the ink chamber, so that ink liquid in the ink chamber is discharged out of the ink chamber through the nozzle opening, the pressure generating member comprising: a buckling member which is formed into a generally plate shape, where portions forming both ends in at least one direction out of a peripheral portion of the buckling member are attached to the substrate, and which buckling member is switchable between a no-displacement state in which the buckling member undergoes substantially no thermal stress, and a buckling state in which the buckling member is buckled through thermal expansion; and a heater layer which is provided along one surface of the buckling member and which generates heat through electrical energization.

The ink jet head with the above arrangement is driven in the following fashion. That is, the ink chamber is previously filled with ink for an operation. During a

heating period, the heater layer is electrically energized to generate heat. The buckling member, receiving this heat from the heater layer, turns from a no-displacement state into a buckled state due to thermal expansion. As a result, the pressure generating member including the buckling member and the heater layer is deformed as a whole so that a pressure is generated in the ink chamber. This pressure causes the ink liquid within the ink chamber to be discharged out of the chamber through the nozzle opening of the nozzle plate. Upon the entrance into a cooling period, the heater layer is stopped from being energized. Then, the buckling member is cooled so as to be restored to the original no-displacement state together with the heater layer. As a result, the pressure generating member as a whole is restored to the original position. Such heating period and cooling period are repeated, whereby the pressure generating member is repeatedly deformed and restored.

In this ink jet head, the substrate is present on a side of the pressure generating member opposite to the side on which the nozzle plate is provided (hereinafter, referred to as "rear side"). As the material of this substrate, actually, one having a thermal conductivity larger than that of ink by one order or more may be readily selected. In such a selection, after a heating period and upon the entrance into a cooling period, heat of the pressure generating member, especially of the buckling member and the heater layer, is discharged out of the ink chamber rapidly through the substrate. Accordingly, the cooling rate of the pressure generating member becomes a high rate. As a result of this, a good response characteristic is obtained so that high-speed printing becomes possible. Also, since the buckling member and the heater layer, which constitute the pressure generating member, are provided by independent layers, the heater layer may be shaped into a narrow pattern irrespectively of the shape of the buckling member. Such an arrangement saves the amount of current for energization involved in obtaining a required amount of heat so that the power consumption is reduced.

Also, there is provided an ink jet head which comprises: an ink chamber including a as part of its peripheral wall a nozzle plate having a nozzle opening, and a substrate opposed to the nozzle plate; and a pressure generating member provided in the ink chamber and opposed to the nozzle plate, wherein the pressure generating member is deformed to generate a pressure within the ink chamber, so that ink liquid in the ink chamber is discharged out of the ink chamber through the nozzle opening, the pressure generating member comprising: a buckling member which is formed into a generally plate shape, where portions forming both ends in at least one direction out of a peripheral portion of the buckling member are attached to the substrate, and which buckling member is switchable between a no-displacement state in which the buckling member undergoes substantially no thermal stress, and a buckling state in which the buckling member is buckled through thermal expansion; and a diaphragm which is composed of a generally plate-shaped flexible material, and which is provided along one surface of the buckling member on the nozzle plate side out of both surfaces of the buckling member in such a state that a peripheral portion of the diaphragm is attached to the peripheral portion of the buckling member.

The ink jet head with the above arrangement is driven in the following fashion. That is, the ink chamber is previously filled with ink for an operation. During a heating period, the buckling member is electrically energized to generate heat. The buckling member, by this heat generation, turns from a no-displacement state into a buckled state due to thermal expansion. The diaphragm provided along a surface of the buckling member on the nozzle plate side (hereinafter, referred to as "front surface") is composed of a flexible material, and therefore will be flexed and deformed in response to a pressing force due to deformation of the buckling member. That is, the pressure generating member including the buckling member and the diaphragm is deformed as a whole so that a pressure is generated in the ink chamber. This pressure causes the ink liquid within the ink chamber to be discharged out of the chamber through the nozzle opening of the nozzle plate. Upon the entrance into a cooling period, the heater layer is stopped from being energized. Then, the buckling member is cooled so as to be restored to the original no-displacement state. The diaphragm, now free from the pressing force from the buckling member, is restored to the original state by its own restoring force. That is, the pressure generating member as a whole is restored to the original position. Such heating period and cooling period are repeated, whereby the pressure generating member is repeatedly displaced and restored.

In this ink jet head, the substrate is present on the rear side of the pressure generating member. As the material of this substrate, actually, one having a thermal conductivity larger than that of ink by one order or more may be readily selected. In such a selection, after a heating period and upon the entrance into a cooling period, heat of the pressure generating member, especially of the buckling member, is discharged out of the ink chamber rapidly through the substrate. Accordingly, the cooling rate of the pressure generating member becomes a high rate. As a result of this, a good response characteristic is obtained so that high-speed printing becomes possible. Also, thanks to the diaphragm, the ink present in a clearance between the nozzle plate and the pressure generating member (diaphragm) can be prevented from going around to the rear side of the pressure generating member (diaphragm) during an operation. As a result, the discharge force and discharge rate of ink become large. Further, since the buckling member and the diaphragm, which constitute the pressure generating member, are provided separately, the buckling member may be shaped irrespectively of the shape of the diaphragm. For example, it becomes possible to form slits in the buckling member. Such an arrangement allows the buckling member to be rapidly cooled by circulating the refrig-

erant such as ink through the buckling member on the rear side of the diaphragm, as described later. As a result, an even better response characteristic can be obtained so that high-speed printing becomes possible.

In one embodiment of the present invention, there is provided the pressure generating member further comprises: a diaphragm which is composed of a generally plate-shaped flexible material, and which is provided along one surface of the buckling member on the nozzle plate side out of both surfaces of the buckling member in such a state that a peripheral portion of the diaphragm is attached to the peripheral portion of the buckling member.

The ink jet head with the above arrangement is driven in the following fashion. That is, the ink chamber is previously filled with ink for an operation. During a heating period, the heater layer is electrically energized to generate heat. The buckling member, receiving this heat from the heater layer, turns from a no-displacement state into a buckled state due to thermal expansion. As a result, the pressure generating member including the buckling member, the heater layer, and the diaphragm is deformed as a whole so that a pressure is generated in the ink chamber. This pressure causes the ink liquid within the ink chamber to be discharged out of the chamber through the nozzle opening of the nozzle plate. Upon the entrance into a cooling period, the heater layer is stopped from being energized. Then, the buckling member is cooled so as to be restored to the original no-displacement state together with the heater layer. The diaphragm, now free from the pressing force from the buckling member, is restored to the original state by its own restoring force. As a result, the pressure generating member as a whole is restored to the original position. Such heating period and cooling period are repeated, whereby the pressure generating member is repeatedly displaced and restored.

In this ink jet head, the substrate is present on the rear side of the pressure generating member. As the material of this substrate, actually, one having a thermal conductivity larger than that of ink by one order or more may be readily selected. In such a selection, after a heating period and upon the entrance into a cooling period, heat of the pressure generating member, especially of the buckling member and the heater layer, is discharged out of the ink chamber rapidly through the substrate. Accordingly, the cooling rate of the pressure generating member becomes a high rate. As a result of this, a good response characteristic is obtained so that high-speed printing becomes possible. It is noted that the case is unchanged even if an ink layer is present more or less between the substrate and the pressure generating member. Also, since the buckling member and the heater layer, which constitute the pressure generating member, are provided by independent layers, the heater layer may be shaped into a narrow pattern irrespectively of the shape of the buckling member. Such an arrangement saves the amount of current for energization involved in obtaining a required amount of heat so that the power consumption is reduced. Further, thanks to the diaphragm, the ink present in a clearance between the nozzle plate and the pressure generating member (diaphragm) can be prevented from going around to the rear side of the pressure generating member (diaphragm) during an operation. As a result, the discharge force and discharge rate of ink become large so that practical operating characteristics can be obtained. Further, since the buckling member and the diaphragm, which constitute the pressure generating member, are provided separately, the buckling member may be shaped irrespectively of the shape of the diaphragm. For example, it becomes possible to form slits in the buckling member. Such an arrangement allows the buckling member and the heater layer to be rapidly cooled by circulating the refrigerant such as ink through the buckling member on the rear side of the diaphragm, as described later. As a result, an even better response characteristic can be obtained so that high-speed printing becomes possible.

In the ink jet head of one embodiment, the heater layer is provided along one surface of the buckling member on the substrate side (hereinafter, referred to as "rear surface") out of both surfaces of the buckling member. In this case, after a heating period and upon the entrance into a cooling period, the heater layer that has been heated to a high temperature particularly out of the pressure generating member is rapidly cooled through the substrate. Accordingly, the cooling rate of the pressure generating member becomes a high rate. As a result, an even better response characteristic can be obtained so that high-speed printing becomes possible.

In the ink jet head of one embodiment, the pressure generating member has a first insulating layer provided between the substrate and the heater layer. Such an arrangement allows the substrate and the heater layer to be successfully insulated from each other so that the current flowing through the heater layer will never leak to the substrate. As a result, the amount of current required to obtain the necessary heat generation can be saved so that the power consumption can be reduced.

In the ink jet head of one embodiment, the pressure generating member has a second insulating layer provided between the buckling member and the heater layer. Such an arrangement allows the buckling member and the heater layer to be successfully insulated from each other so that the current flowing through the heater layer will never leak to the buckling member. As a result, the amount of current required to obtain the necessary heat generation can be saved so that the power consumption can be reduced.

In the ink jet head of one embodiment, since the diaphragm is formed into a generally disc shape, the volumetric variation of the ink chamber (a clearance between the nozzle plate and the pressure generating member) becomes large for a small surface area of the diaphragm. This is because the portion that is displaced by being pushed by the buckling member is limited to a circular area about the portion with which the buckling member

is in contact, however the surface area of the diaphragm is wide. For example, when the diaphragm is formed into a rectangular plate shape, the portions in proximity to the rectangular corners will never displace and therefore will not contribute to the volumetric variation of the ink chamber. In contrast to this, when the diaphragm is formed into a generally disc shape, the entire surface of the diaphragm contributes to the volumetric variation of the ink chamber. Accordingly, as described above, the volumetric variation of the ink chamber becomes large for the small surface area of the diaphragm. As a result of this, the discharge force and discharge rate become large for the small surface area of the diaphragm. Conversely, when the discharge force of ink is larger than necessary, the ink jet head may be miniaturized by reducing the diameter of the diaphragm.

In the ink jet head of one embodiment, at least part of the diaphragm other than the peripheral portion is coupled to the buckling member. With such an arrangement, when the buckling member is going to restore to the original position after a heating period and upon the entrance into a cooling period, the diaphragm undergoes a tensile force from the buckling member in addition to its own restoring force. As a result of this, the diaphragm restores to the original position faster. Accordingly, the response characteristic of the pressure generating member is improved so that high-speed printing is enabled.

In the ink jet head of one embodiment, the center portion of the diaphragm is coupled to the center portion of the buckling member. With such an arrangement, a portion (center portion) that has been displaced to the most extent out of the diaphragm during a heating period is pulled by a portion (center portion) that restores fastest out of the buckling member upon the entrance into a cooling period. As a result, the diaphragm restores to the original position even faster. Accordingly, the response characteristic of the pressure generating member is improved so that high-speed printing is enabled.

In the ink jet head of one embodiment, a clearance is provided between an intermediate portion between the peripheral portion and the center portion coupled to the buckling member out of the diaphragm, and the buckling member. Therefore, it becomes possible to rapidly cool the buckling member by circulating the refrigerant such as ink through the clearance between the diaphragm and the buckling member, on the rear side of the diaphragm. As a result, an even better response characteristic is obtained so that high-speed printing is enabled.

In the ink jet head of one embodiment, a clearance is provided between a portion of the buckling member inner than its peripheral portion out of the pressure generating member, and the substrate. Therefore, it becomes possible to rapidly cool the buckling member and the heater layer by circulating the refrigerant such as ink through the clearance between the buckling member and the substrate, on the rear side of the diaphragm. As a result, an even better response characteristic is obtained so that high-speed printing is enabled.

In the ink jet head of one embodiment, the distance between the substrate and the aforementioned portion of the pressure generating member is set to within a range of 0.05 µm to 2.0 µm. Such an arrangement allows the clearance between the substrate and the pressure generating member to be easily formed, and also allows the response characteristic of the pressure generating member to be maintained good. That is, if the distance of the clearance is 0.05 µm or more, the clearance can be formed by stacking the material of a sacrifice layer (a layer for processing) and that of the pressure generating member on the substrate one by one, and by removing the sacrifice layer with an etchant. In contrast to this, if the distance of the clearance is less than 0.05 µm, then it is difficult to penetrate the etchant through the clearance and therefore difficult to form the clearance. Further, if the interval of the clearance is 2.0 µm or less, heat of the pressure generating member, especially of the buckling member and the heater layer, can be discharged rapidly out of the ink chamber through the substrate during a cooling period. Accordingly, the response characteristic of the pressure generating member can be maintained good. In contrast, if the distance of the clearance exceeds 2.0 µm, then the heat radiation passing through the substrate becomes a small one, so that the response characteristic of the pressure generating member deteriorates noticeably.

In the ink jet head of one embodiment, a slit is provided at a portion of the pressure generating member inner than the peripheral portion of the buckling member, so as to be bored through from the surface opposite to the substrate to the diaphragm side surface of the buckling member. Therefore, the buckling member can be rapidly cooled by circulating the refrigerant such as ink through the slit on the rear side of the diaphragm. In particular, when clearances are provided between the diaphragm and the buckling member and between the substrate and the pressure generating member, these clearances communicate with each other through the slit so that the cooling effect is enhanced. As a result, the response characteristic is further improved so that high-speed printing is enabled.

In the ink jet head of one embodiment, a plurality of slits as described above are provided, and it is arranged that a strip-shaped portion of the buckling member sandwiched by the slits will be buckled. In this arrangement, for example, by attaching the entire peripheral portion of the buckling member to the substrate, thermal stress of the buckling portion due to repeated heating and cooling can be received by the entire peripheral portion. That is, the thermal stress of the strip-shaped portion sandwiched by the slits is generated outward one way in a direction in which the strip-shaped portion extends. This unidirectional outward force is applied to particular portions of the peripheral portion, but is received also by portions adjacent to the particular portions out of the peripheral portion. Accordingly, the thermal stress of the buckling portion is not applied only to particular portions, but relaxed and received by the entire peripheral portion.

As a result, the place where the substrate and the buckling member are fitted to each other becomes less subject to damage, so that the ink jet head is prolonged in its service life.

In the ink jet head of one embodiment, the substrate is provided with a refrigerant circulation hole which is bored through the substrate and which confronts a portion of the pressure generating member inner than the peripheral portion of the buckling member. Such an arrangement allows the refrigerant such as ink to be fed from one side of the substrate opposite to the side on which the pressure generating member is provided (hereinafter, referred to as "rear side") to the other side of the substrate on which the pressure generating member is provided (hereinafter, referred to as "front side"), through the refrigerant circulation hole. The fed refrigerant circulates between the front and rear sides of the substrate as the pressure generating member is displaced and restored by heating and cooling. Accordingly, it becomes possible to rapidly cool the pressure generating member. This fact is particularly significant when the ink is prevented from going around to the rear side of the diaphragm by the diaphragm being provided. Also, when a clearance is provided between the diaphragm and the buckling member or between the substrate and the pressure generating member, or when slits bored through from the surface opposite to the substrate to the diaphragm-side surface of the buckling member are provided at portions of the pressure generating member inner than the peripheral portion of the buckling member, the refrigerant circulates through the clearances or slits so that the cooling effect can be enhanced. As a result, an even better response characteristic is obtained so that high-speed printing is enabled.

In the ink jet head of one embodiment, the refrigerant circulation hole is so arranged that its size gradually decreases from the rear side toward the front side of the substrate. With such an arrangement, the opposing area between the pressure generating member and the substrate surface is less reduced as compared to when the refrigerant circulation hole is not provided. Accordingly, after a heating period and upon the entrance into a cooling period, heat of the pressure generating member, especially heat of the buckling member, is discharged rapidly out of the ink chamber through the substrate. As a result, the cooling rate of the pressure generating member is maintained high, so that the response characteristic is maintained good.

In the ink jet head of one embodiment, a refrigerant reservoir communicating with the refrigerant circulation hole is formed on the rear side of the substrate. Such an arrangement allows the refrigerant such as ink to be fed to the front side of the substrate from the refrigerant reservoir through the refrigerant circulation hole.

Also, there is provided a method for fabricating an ink jet head which comprises: an ink chamber including as part of its peripheral wall a nozzle plate having a nozzle opening, and a substrate opposed to the nozzle plate; and a pressure generating member provided in the ink chamber and opposed to the nozzle plate, wherein the pressure generating member comprises a plate-shaped buckling member, a heater layer provided on one side of the buckling member on which the substrate is provided, and a diaphragm provided on one side of the buckling member on which the nozzle plate is provided, the method comprising the steps of: forming a first sacrifice layer having a pattern occupying a specified closed area on a surface of the substrate; forming a first insulating layer composed of a material that can be etched selectively with the first sacrifice layer in such a manner that the first insulating layer covers the first sacrifice layer; forming on the first insulating layer a heater layer having a pattern passing through an area occupied by the first sacrifice layer; forming a second insulating layer composed of a material that can be etched selectively with the first sacrifice layer in such a manner that the second insulating layer covers the above-formed layers; forming slits along both sides of the pattern of the heater layer in such a manner that the slits extend from a front surface of the second insulating layer to a front surface of the first sacrifice layer; burying interiors of the slits by applying resist onto the substrate and by performing photolithography, and forming a resist wall that protrudes from the front surface of the second insulating layer by a specified height with its width kept equal to that of the slits; forming on the second insulating layer a first metal layer for constituting the buckling member, by a plating process into a specified thickness which does not exceed the height of the resist wall; forming a second sacrifice layer composed of a material that can be etched selectively with the first metal layer, on a closed area generally corresponding to the first sacrifice layer in such a manner that the second sacrifice layer covers a specified portion of a front surface of the first metal layer as well as the slits; forming a second metal layer serving for constituting the diaphragm and composed of a material that can be etched selectively with the second sacrifice layer, all over so that the second metal layer covers the above-formed layers on the surface of the substrate; boring a hole reaching the first sacrifice layer on the front surface side of the substrate by performing etching from a rear surface side of the substrate, etching and thereby removing the first sacrifice layer through the hole selectively with the first and second insulating layers, and subsequently removing the resist wall, and further etching and thereby removing the second sacrifice layer through the slits generated by removing the resist wall selectively with the first and second metal layers; and forming the diaphragm having a specified configuration by patterning the second metal layer.

According to the above method for fabricating the ink jet head, since the pressure generating member can be fabricated by semiconductor integrating processes, the ink jet head can be fabricated into small size. Further, two clearances, i.e., one clearance between the substrate and the pressure generating member and the other clearance between the buckling member and the diaphragm in the pressure generating member, can be

collectively fabricated by etching and removing continuously the first sacrifice layer and the second sacrifice layer. Accordingly, the fabrication processes can be simplified. Yet, the two clearances are formed in response to the thicknesses of the first sacrifice layer and the second sacrifice layer, respectively, so that the sizes of the clearances are set with high accuracy.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will become more fully understood from the detailed description given hereinbelow and the accompanying drawings which are given by way of illustration only, and thus are not limitative of the present invention, and wherein:

Fig. 1 is a sectional view showing an overall construction of an ink jet head of the present invention;
Fig. 2 is a view for explaining operation of the ink jet head;
Fig. 3 is a perspective view showing the ink jet head in an exploded state;
Fig. 4 is an exploded perspective view showing in detail a buckling member and a heater layer on its rear side and others in Fig. 3;
Fig. 5 is a view showing main part of the ink jet head;
Fig. 6 is a view schematically showing a construction of an apparatus used for simulations of heat radiation characteristics;
Figs. 7A and 7B are a diagram showing a drive waveform for driving the buckling member with drive conditions 1, and a chart showing time variation of displacement ΔZ and increased temperature ΔT of a center portion of the buckling member, respectively;
Figs. 8A and 8B are charts showing the dependency of response speed on an interval A between a surface protective film of the substrate and a first insulating film, and the dependency of response speed on the thickness B of the first insulating film;
Figs. 9A and 9B are a chart showing the dependency of response speed on a thickness C of the second insulating film, and the dependency of response speed on a clearance D between the buckling member and a diaphragm;
Fig. 10 is a plan view schematically showing construction of a model used for fluid analysis simulations;
Fig. 11 is a schematic sectional view taken along a line 11 - 11 of Fig. 10;
Figs. 12A, 12B, and 12C are views showing the dependency of ink discharge velocity on the length F, width G, and depth H of an ink feed passage, respectively;
Fig. 13A is a diagram showing the drive waveform for driving the buckling member with drive conditions 2, and Fig. 13B is a chart showing the time variation of displacement ΔZ and increased temperature ΔT of the center portion of the buckling member;
Fig. 14 is a chart showing the dependency of discharge velocity V on power consumption per unit volume W of the buckling member;
Figs. 15A, 16A, 17A, 18A, 19A, 20, 21A, 23A, 24A, 25A, 26A, 27A, 28A, 30A, and 31A are process views for explaining a method of fabricating an ink jet head which is an embodiment of the present invention, in correspondence to a cross section along the line X_1 - X_1 of Fig. 3;
Figs. 15B, 16B, 17B, 18B, 19B, 21B, 22, 23B, 24B, 25B, 26B, 27B, 28B, 29, 30B, and 31B are process views for explaining the method of fabricating an ink jet head which is an embodiment of the present invention, in correspondence to a cross section along the line Y_1 - Y_1 of Fig. 3; and
Fig. 32 is a sectional view showing the construction of the conventional ink jet head.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The ink jet head of the present invention and its fabricating method are described in more detail hereinbelow by embodiments thereof.

Fig. 1 shows an overall construction of an ink jet head 90 which is an embodiment. This ink jet head 90 has a substrate 7 including a surface protective film 6. On the front surface side of the substrate 7, provided are a first insulating film 2 as a first insulating layer, a heater layer 3, a second insulating film 4 as a second insulating layer, a buckling member 1, and a diaphragm 5, one by one. The first insulating film 2, the heater layer 3, the second insulating film 4, the buckling member 1, and the diaphragm 5 constitute a pressure generating member 20. Also on the front surface side or the substrate 7, a nozzle plate 10 is mounted so as to be opposed to the diaphragm 5 via a spacer 8. Electrode pads 13a, 13b are provided on both sides of the buckling member 1. Meanwhile, on the rear surface side of the substrate 7, a housing 9 is provided and a refrigerant reservoir 34 is formed by the housing 9 on the rear surface side of the substrate 7.

Fig. 3 shows the ink jet head in an exploded state as viewed obliquely. Fig. 4 shows the buckling member 1 as well as the first insulating film 2, the heater layer 3, and the second insulating film 4 present in the rear of the buckling member 1 (omitted in Fig. 3). Although the substrate 7, the buckling member 1, and the first insulating film 2 and second insulating film 4 are represented each in a rectangular form in Figs. 3 and 4, they may actually be extended peripherally (except the areas of the electrode pads 13a, 13b).

As shown in Fig. 3, the substrate 7 is formed of a silicon (Si) plate having a silicon oxide film, which is formed by thermal oxidation in this case, as the surface protective film 6. The thermal conductivity of the substrate 7 is around 70 $W \cdot m^{-1} \cdot K^{-1}$. The film thickness of the surface prot ctiv film 6 is desirably thicker to ensure the insulating property, but desirably thinner for

thermal conduction. As a conclusion, the film thickness of the surface protective film 6 is set within a range of 0.5 to 1 µm. A refrigerant circulation hole 16 is bored generally in the center of the substrate 7. The refrigerant circulation hole 16 is a hole bored through the substrate 7 and having a rectangular cross section, where the dimensions of the sides of the rectangular shape of the refrigerant circulation hole 16 (dimensions in cross section) are so set as to gradually decrease from the rear toward the front side of the substrate 7. This setting is intended to minimize the loss of the area at which the pressure generating member 20 is, or especially the buckling member 1 and the heater layer 3 are, opposed to the front surface of the substrate 7. In this way the pressure generating member 20 and the substrate 7 are opposed to each other over a large area, so that heat of the pressure generating member 20, especially of the buckling member 1 and the heater layer 3, can be discharged out of the ink chamber through the substrate 7 with high efficiency in operation.

The buckling member 1 is made of a metal material (whose thickness is assumed to be "t") such as nickel. In more detail, the buckling member 1 is formed into a two-layer structure in which 0.01 µm thick tantalum with a small linear coefficient of expansion is disposed on the substrate 7 side while 6 µm thick nickel with a large lineal coefficient of expansion is disposed on the nozzle plate 10 side, in order that the buckling member 1, when buckling due to thermal expansion, will be deformed toward the nozzle plate 10 side.

The first insulating film 2 and the second insulating film 4 (Fig. 4) are made of an insulating material such as silicon oxide or alumina. The first insulating film 2 and the second insulating film 4 prevent the current flowing through the heater layer 3 from leaking into the substrate 7 or the buckling member 1. Thus, the power consumption can be reduced.

As shown in Fig. 4, the buckling member 1, the first insulating film 2, and the second insulating film 4 have four L-shaped slits 40 bored through their rectangular planes. The four slits 40 are arranged so as to be separated from one another with the bent portion of the L pointed to the center. As a result, cross-shaped portions 2a, 4a, and 1a are formed in center portions of the first insulating film 2, the second insulating film 4, and the buckling member 1, respectively. In particular, terminal ends of the side lines 1b (length L, width W) of the cross-shaped portion 1a of the buckling member 1 are supported by a peripheral portion 1c of the buckling member 1, so that the buckling member 1 is actually buckled when the side lines 1b of the cross-shaped portion 1a are heated. In this shape of the buckling member 1, with the peripheral portion 1c provided on the substrate 7 over its entire periphery, thermal stress of the buckling portions 1b due to repeated heating and cooling processes can be received by the whole peripheral portion 1c. That is, the thermal stress of the side lines 1b of the cross-shaped portion 1a is generated outward in their longitudinal direction. This thermal stress applies to places adjoining to the side lines 1b of the peripheral portion 1c, and moreover to portions of the peripheral portion 1c adjoining to the places. Therefore, the thermal stress of the side lines 1b of the cross-shaped portion 1a can be relaxed and received by the whole peripheral portion 1c. Thus, the place where the substrate 7 and the buckling member 1 are fitted to each other is subject to less damage, so that the service life of the ink jet head can be prolonged.

The heater layer 3 is made from, for example, nickel or nickel chromium alloy or other like materials. The heater layer 3 has strip-shaped electrode portions 3c, 3c extending in parallel around the first and second insulating films 2, 4; a circular portion 3a sandwiched by the center portions (crossing portions of the side lines 1b) of the cross-shaped portions 2a, 4a of the first and second insulating films 2, 4; and a strip-shaped resistance portion 3b which is sandwiched by the side lines 1b of the cross-shaped portions 2a, 4a of the first and second insulating films 2, 4 and which is meandered in U-shape to connect the electrode portions 3c, 3c and the circular portion 3a with each other. The electrode pads 13a, 13b made of the same layer as the buckling member 1 are connected onto the electrode portions 3c, 3c. As seen above, since the buckling member 1 and the heater layer 3, which constitute the pressure generating member 20, are provided by independent layers, the heater layer 3 can be formed into a narrow pattern irrespectively of the shape of the buckling member 1. Therefore, the amount of electrical energization required for necessary quantity of heat generation can be reduced so that the power consumption can be reduced.

As shown in Fig. 3, the diaphragm 5 is made of an elastic material such as nickel and formed into a generally disc shape (with diameter E). Thanks to this diaphragm 5, ink 15 present in a clearance 31 between the nozzle plate 10 and the pressure generating member 20 as shown in Fig. 1 can be prevented from going around to the rear side of the pressure generating member 20 during an operation. Accordingly, the discharge force and discharge velocity of ink can be increased and, as a result, practical operating characteristics can be obtained. In particular, since this diaphragm 5 is formed into a generally disc shape, the volumetric variation of the ink chamber (clearance) 31 is large for a small surface area of the diaphragm 5. This is because, however large the surface area of the diaphragm is, the portion that is displaced with a push by the buckling member 1 is limited to the circular area about the place with which the buckling member 1 makes contact. As a result, the discharge force and discharge velocity of ink can be made large for the small surface area of the diaphragm 5.

The spacer 8 is made of an insulating film material such as polyimide or acrylic photosensitive adhesives having a specified thickness. This spacer 8 has a through hole 8a drilled into a circular shape in order to form the clearance 31 in which ink should be filled between the diaphragm 5 and the nozzle plate 10. Also, to feed ink into th clearance 31, provided is an ink f ed passage

plate 10. By this injection of the ink droplet 15a, the print surface provided opposite to the nozzle plate 10 is performed is printed.

It is noted that while the buckling member 1 and the diaphragm 5 are displaced toward the nozzle plate 10, the ink 15 that has been present in the refrigerant reservoir 34 flows into the clearance 32 between the substrate 7 and the first insulating film 2 through the refrigerant circulation hole 16, and further flows into the clearance 33 between the buckling member 1 and the diaphragm 5 through the slits 40.

(3) Subsequently, the switch 52 is returned to the ground side, whereby the heater layer is stopped from being energized (cooling period). Then, the buckling member 1 is cooled, going to restore to the original no-displacement state together with the heater layer 3. When the buckling member 1 is going to restore to the original position, the diaphragm 5 undergoes a tensile force from the buckling member 1 in addition to the restoring force of its own. In particular, since the center portion 5a of the diaphragm 5 is coupled to the center portion 1a of the buckling member 1, the portion of the diaphragm 5 that has been displaced most in the heating period, or the center portion 5a, is tensed by the portion of the buckling member 1 that restores fastest, or the center portion 1a. As a result, the diaphragm 5 fast restores to the original position. Thus, the pressure generating member 20 restores to the original position as a whole (standby state). Such heating period and cooling period are repeated, whereby the pressure generating member 20 is repeatedly displaced and restored.

In this connection, the refrigerant that flowed into the clearances 32, 33 and slits 40 through the refrigerant circulation hole 16 in the step (2) circulates between the rear and front sides of the substrate 7 as the pressure generating member 20 is displaced and restored by heating and cooling. The refrigerant thus contributes to the discharge of heat. Yet, the present ink jet head 90 has the substrate 7 present on the rear side of the pressure generating member 20. The thermal conductivity of the substrate 7 is about 70 $W \cdot m^{-1} \cdot K^{-1}$, greater than that of the ink 15 by two orders or more. Therefore, after the heating period and upon an entrance into the cooling period, the heat of the buckling member 1 and the heater layer 3 is discharged rapidly out of the ink chamber through the substrate 7 (including the surface protective film 6). Accordingly, the pressure generating member 20, particularly the buckling member 1 and the heater layer 3 can be rapidly cooled. As a result of this, a better response characteristic is obtained so that fast printing is enabled.

Next described is the results of examining the performance of the ink jet head 90 by simulations.

(1) First, with this ink jet head 90, a simulation on the displacement and increased temperature of the center portion 5a of the diaphragm 5 was performed.

Fig. 6 outlines the construction of the device used in this simulation. In this device, a portion 91 pertinent to thermal response characteristics of the ink jet head 90 is accommodated in a container 99 for defining the boundary conditions in this simulation. The dimensions of the container 99 are set larger than the outer dimensions of the portion 91 pertinent to the thermal response characteristics by the degree of 20 µm each. As the configuration of the portion 91 pertinent to the thermal response characteristics, which configuration serves as the reference for setting the dimensions of the container 99, based on the fact that the buckling member 1 deforms 9 µm toward the nozzle plate 10 for a 100 degree temperature increase of the buckling member 1, such a configuration was adopted that the center portion 1a of the buckling member 1 deformed the average of 4.5 µm. It is noted that the temperature increase was set to 100 degrees because in another energy calculation the energy required to discharge the ink droplet was set to ten times larger the sum of "kinetic energy + surface energy" of the ink droplet. With the interior of the container 99 filled with the ink 15, the simulation was performed on the assumption that the inner surface of the container 99 and the rear side of the substrate 7 would be maintained at 0°C. In Fig. 6, the arrows directed from the heater layer 3 toward the rear side of the substrate 7 show principal discharge paths of heat.

Fig. 5 illustrates the way of setting parameters for the portion 91 pertinent to the thermal response characteristics in this simulation. Reference character A denotes the size of the clearance 32, or the interval between the surface protective film 6 of the substrate 7 and the first insulating film 2. B denotes the thickness of the first insulating film 2, and C denotes the thickness of the second insulating film 4. Further, D denotes the size of the clearance 33, or the interval between the buckling member 1 and the diaphragm 5.

Also, the length L of the side lines 1b of the buckling member 1 (not including the central crossed portion out of the cross-shaped portion 1a) as shown in Fig. 4 was set to 250 µm. The width W of the buckling member 1 was set to 92 µm and its thickness T was set to 5 µm. Further, although the number of side lines 1b of the buckling member 1 (number of side lines of the buckling portion) was four in Fig. 4, this simulation was performed on the assumption that eight of the side lines were present in a radial configuration. Also, the diameter E of the diaphragm was set to 800 µm, and the thickness of the heater layer 3 was set to 0.1 µm.

(i) First, the parameter A was set to 0.5 µm, B was 0.5 µm, C was 0.5 µm, and D was 0.5 µm.

Also, as the drive conditions, the buckling member 1 was set as follows (drive conditions 1):

- energy consumption per unit volume to 7.6×10^{8} J/m^3;
- power consumption per unit volume to 4×10^{13} W/m^3; and
- pulse width to 19 µs.

Fig. 7A shows the drive waveform corresponding to the drive conditions 1. Fig. 7B charts the displacement ΔZ and increased temperature ΔT of the center portion 1a of the buckling member 1 versus elapsed time, obtained by simulated calculation with the drive conditions 1. Fig. 7B also charts time transition of increased time ΔT_{INK} of the ink present on the surface of the diaphragm 5 in addition. Calculating the response speed from the increased temperature curve ΔT of the buckling member 1 yields a leading-edge response speed (tr) of 19 µs and a trailing-edge response speed (td) of 101 µs. Therefore, it can be understood that the drive with a drive frequency of 8.3 kHz is possible.

The reason why the drive frequency can be made so high as above is that the trailing-edge response speed (td) is relatively high. That is, the heat of the buckling member 1 and the heater layer 3 is fast discharged outside after conducted by the ink 15 that is passed through the refrigerant circulation hole 16 and then goes in and out between the clearance 32 and the rear side of the substrate 7, and further conducted by the substrate 7 having the surface protective film 6. Also, the substrate 7 having a high thermal conductivity is located in proximity to the buckling member 1. This arrangement allows a high trailing-edge response speed (td) and a high drive frequency.

(ii) Next, under the same drive conditions 1, the parameter A was changed from 0.1 to 2.0 µm while the parameter B was held at 0.5 µm, C at 0.5 µm, and D at 0.5 µm.

Fig. 8A shows a variation of the response speed that occurred in this case. The leading-edge response speed (tr) becomes slightly higher with increasing A. Meanwhile, the trailing-edge response speed (td) becomes markedly lower with increasing A. As can be understood from Fig. 8A, drive at a drive frequency of 5.5 kHz is possible when A is 2 µm or less. Drive at a drive frequency of 6.8 kHz is possible when A is 1 µm or less.

This parameter A, or the distance of the clearance 32, is actually set to within a range of 0.05 µm to 2.0 µm. The reason of this is that if the distance of the clearance 32 is 0.05 µm or more, the clearance 32 can be easily formed, as described later, through steps of laminating the materials of a sacrifice layer (a layer for processing) and the pressure generating member 20 one by one on the substrate 7 and then removing the sacrifice layer with an etchant. In contrast to this, if the distance of the clearance 32 is less than 0.05 µm, the etchant could not be easily penetrated therethrough so that the clearance 32 becomes difficult to form. Also, if the distance of the clearance 32 is over 2.0 µm, the heat radiation effect through the substrate 7 is reduced so that the response characteristic of the pressure generating member 20 cannot be improved.

(iii) Next, under the same drive conditions 1, the parameter B was changed from 0.1 to 1.0 µm while the parameter A was held at 0.5 µm, C at 0.5 µm, and D at 0.5 µm.

Fig. 8B shows a variation of the response speed that occurred in this case. The leading-edge response speed (tr) becomes slightly higher with increasing the parameter B. Meanwhile, the trailing-edge response speed (td) becomes markedly lower with increasing the parameter B. As can be understood from Fig. 8B, drive at a drive frequency of 7.6 kHz is possible when B is 1 µm or less. Drive at a drive frequency of 8.3 kHz is possible when B is 0.5 µm or less. In addition, the parameter B, or the thickness of the first insulating film 2, may also be actually set to 0.1 µm or less.

(iv) Next, under the same drive conditions 1, the parameter C was changed from 0.1 to 1.0 µm while the parameter A was held at 0.5 µm, B at 0.5 µm, and D at 0.5 µm.

Fig. 9A shows a variation of the response speed that occurred in this case. The leading-edge response speed (tr) becomes slightly lower with increasing C. Meanwhile, the trailing-edge response speed (td) becomes also slightly lower with increasing C. As can be understood from Fig. 9A, drive at a drive frequency of 8 kHz is possible when C is 1 µm or less. Drive at a drive frequency of 8.3 kHz is possible when C is 0.5 µm or less. In addition, the parameter C, or the thickness of the second insulating film 4, may also be actually set to 0.1 µm or less.

(v) Next, under the same drive conditions 1, the parameter D was changed from 0.1 to 2.0 µm while the parameter A was held at 0.5 µm, B at 0.5 µm, and C at 0.5 µm.

Fig. 9B shows a variation of the response speed that occurred in this case. The leading-edge response speed (tr) becomes higher with increasing D. Meanwhile, the trailing-edge response speed (td) becomes markedly higher

with increasing D. As can be understood from Fig. 9B, drive at a drive frequency of 6.7 kHz is possible when D is 0.1 μm. Drive at a drive frequency of 8.3 kHz is possible when D is 0.5 μm. In particular, drive at a drive frequency of 10 kHz is possible when D is 1.0 μm or more. In addition, the parameter D, or the distance of the clearance 33 between the buckling member 1 and the diaphragm 5, may also be actually set to 1.0 μm or more, as described later.

(2) Next, the discharge velocity V of ink droplets of the ink jet head 90 was examined.

The discharge velocity V of ink droplets can be calculated by a simulation with fluid analysis. Fig. 10 is a plan view showing the ink jet head 90 as it is modeled for fluid analysis. Fig. 11 shows a cross section taken along the line 11 - 11 and viewed along the arrows in Fig. 10. It is noted that the nozzle plate is omitted for convenience in Fig. 10, and only the diaphragm 5 out of the pressure generating member 20 is shown in Fig. 11.

In this simulation with fluid analysis, a fluid 15b present on the surface of the diaphragm 5 was given a moving velocity V_0, and a so-called wall-drive model for analyzing the movement of fluid within the ink chamber 31 was used. In this wall-drive model, the diaphragm 5 is first displaced at a velocity of V_0. A pressure thereby developed to the surface of the diaphragm 5 propagates in the fluid 15 toward the nozzle plate 10. By this propagation of pressure, it is assumed that the ink droplet 15a is discharged from the nozzle orifice 11 at a velocity V. It is noted that part of the pressure propagates through the ink feed passage 14 and the refrigerant feed passage 35 shown in Fig. 1 toward the refrigerant reservoir 34.

With the length F, width G, depth H of the ink feed passage changed as parameters, the discharge velocity V was calculated. The drive conditions 1 in the step (1) were adopted as the drive conditions for this calculation. The parameters as shown in Fig. 5 were so set that A was 0.5 μm, B was 0.5 μm, C was 0.5 μm, and D was 0.5 μm.

Fig. 12A shows a variation of the discharge velocity V when the parameter F was changed from 200 μm to 1000 μm while G was set at 40 μm and H at 30 μm. The discharge velocity V becomes higher as the length F of the ink feed passage 14 becomes longer.

Fig. 12B shows a variation of the discharge velocity V when the parameter G was changed from 30 μm to 60 μm while F was set at 200 μm and H at 30 μm. The velocity V becomes lower as the width G of the ink feed passage 14 becomes wider.

Fig. 12C shows a variation of the discharge velocity V when the parameter H was changed from 20 μm to 50 μm while F was set at 200 μm and G at 40 μm. The discharge velocity V becomes lower as the depth H of the ink feed passage 14 becomes deeper.

Consequently, the longer the length F of the ink feed passage 14 and the narrower the opening area (G×H), i.e., the higher the resistance that occurs when the ink 15 flows back along the ink feed passage 14, the faster the ink discharge velocity V. In this connection, from the results of Fig. 12, it was found that if the length F of the ink feed passage 14 is 200 μm or more and the opening area (G×H) is 2000 μm^2 or less, then the ink droplet 15a is discharged at a velocity of 6.7 m/s or more. In particular, if the length F of the ink feed passage 14 is 1000 μm and the opening area (G×H) is 1200 μm^2, then the ink droplet 15a is discharged at a velocity of 15.6 m/s or more.

(3) By using again the device as shown in Fig. 6, a simulation on the displacement and increased temperature of the center portion 5a of the diaphragm 5 was performed with the above ink jet head 90.

In the same way as in the simulation of (1) (i), the length L of the side lines 1b of the buckling member 1 (not including the central crossed portion out of the cross-shaped portion 1a) as shown in Fig. 4 was set to 250 μm. The width W of the buckling member 1 was set to 92 μm and its thickness T was set to 5 μm. Further, although the number of side lines 1b of the buckling member 1 (number of side lines of the buckling portion) was four in Fig. 4, this simulation was performed on the assumption that eight of the side lines were present in a radial configuration. Also, the diameter E of the diaphragm was set to 800 μm, and the thickness of the heater layer 3 was set to 0.1 μm.

Also, as for the parameters as shown in Fig. 5, A was set to 0.5 μm, B was 0.5 μm, C was 0.5 μm, and D was 0.5 μm.

Further, as the drive conditions, the buckling member 1 was set as follows (drive conditions 2):

- energy consumption per unit volume to 7.6×10^8 J/m^3;
- power consumption per unit volume to 8×10^{13} W/m^3; and
- drive pulse width to 9.5 μs.

These drive conditions 2 are such that the energy consumption per unit volume is the same, the power consumption is double, and the pulse width is half relative to the drive conditions 1.

Fig. 13A shows the drive waveform corresponding to the drive conditions 2. Fig. 13B charts the displacement ΔZ and increased temperature ΔT of the center portion 1a of the buckling member 1 versus elapsed time, obtained by simulated calculation with the drive conditions 2. Fig. 13B also charts time transition of increased time ΔT_{INK} of the ink present on the surface of the diaphragm 5 in addition. Calculating the response speed from the increased temper-

ature curve ΔT of the buckling member 1 yields a leading-edge response speed (tr) of 9.5 μs and a trailing-edge response speed (td) of 101 μs. Therefore, it can be understood that the drive with a drive frequency of 9.0 kHz is possible. Since these drive conditions 2 are shorter in pulse width and larger in power consumption than the drive conditions 1, the moving velocity of the buckling member 1 can be made even faster and moreover the drive frequency can be made even higher.

(4) Next, the discharge velocity V of the ink droplet of the ink jet head 90 under the drive conditions 2 was calculated by using the model as shown in Figs. 10 and 11 and by a simulation with fluid analysis.

In the same way as in the simulation of (2), the discharge velocity V was calculated with the length F, width G, and depth H of the ink feed passage changed as parameters. Also, as for the parameters as shown in Fig. 5, parameter A was set to 0.5 μm, B to 0.5 μm, C to 0.5 μm, and D to 0.5 μm.

From the results of this simulation, it was found that if the length F of the ink feed passage 14 is 200 μm or more and the opening area (G×H) is 2000 μm^2 or less, then the ink droplet 15a is discharged at a velocity of 22.9 m/s or more. In particular, if the length F of the ink feed passage 14 is 1000 μm and the opening area (G×H) is 1200 μm^2, then the ink droplet 15a is discharged at a velocity of 31.8 m/s or more. Like this, the discharge velocity of the ink droplet 15a was able to be improved to large extent by adopting the drive conditions 2.

The reason why the discharge velocity V can be so improved as above is that the deformation velocity of the buckling member 1 becomes higher under the drive conditions 2 than under the drive conditions 1. That is, in comparison between the drive conditions 2 and the drive conditions 1, the energy consumption per unit volume of the buckling member 1 is of the same value, but the drive pulse width is smaller and the power consumption is larger in the drive conditions 2 than in the drive conditions 1. For this reason, the deformation velocity of the buckling member 1 becomes raster. As a result, the pressure to the ink 15b becomes larger so that the discharge velocity V of the ink droplet 15a can be improved.

As seen above, in the drive conditions, if the energy consumption per unit volume of the buckling member 1 is unchanged and the power consumption is, for example, doubled, i.e., the drive pulse width is halved, then the discharge velocity of the ink droplet 15a can be made 1.5 times faster.

(5) Next, by using the model as shown in Figs. 10 and 11 and by a simulation with fluid analysis, the discharge velocity V of the ink droplet of the ink jet head 90 was calculated with a wide range of change in the power consumption per unit volume of the buckling member 1 out of the drive conditions.

As for the parameters as shown in Fig. 5, parameter A was set to 0.5 μm, B to 0.5 μm, C to 0.5 μm, and D to 0.5 μm. Also, for the ink feed passage 14 as shown in Figs. 10 and 11, its F was set to 200 μm, G to 40 μm, and H to 30 μm.

Fig. 14 shows the discharge velocity V of the ink droplet that occurred in this case. As seen from Fig. 14, if the power consumption per unit volume W of the buckling member 1 is less than 3×10^{13} W/m^3, then the ink droplet is not discharged (or is discharged unstably). However, if the power consumption W exceeds the threshold 3×10^{13} W/m^3 or so, then the ink droplet starts being discharged, where the discharge velocity V increases with increasing power consumption W. Accordingly, in view of the stability of discharge and the increase in the discharge velocity, the power consumption per unit volume W of the buckling member 1 is desirably set to 4×10^{13} W/m^3 or more.

Also, although the discharge velocity V can be increased by increasing the power consumption per unit volume W of the buckling member 1 as described above, increasing the energy consumption more than necessary in order to increase the power consumption W would cause the temperature of the buckling member 1 to increase too high such that the buckling member 1 would be deteriorated and shortened in life. From this point of view, the energy consumption per unit volume of the buckling member 1 is desirably 4×10^{9} J/m^3 or less for each unit volume, and more desirably 7.6×10^{8} J/m^3 or less.

In addition, the material of the buckling member 1 is not limited to nickel as described above. The material of the buckling member 1 is required only to be large in Young's modulus, large in linear coefficient of expansion, and easy to form a film. Also, the dimensions of the buckling portions 1b of the buckling member 1 are not limited to length L = 250 μm, W = 92 μm, and thickness T = 5 μm. Further, the number of side lines of the buckling member 1 is not limited to four or eight. The number of the buckling portions may also be two or six. Increasing the number of buckling portions in a radial configuration allows the pressure to the ink to be increased so that the discharge velocity of ink droplets can be improved.

Furthermore, the diameter E of the diaphragm is not limited to 800 μm and the thickness of the heater layer is not limited to 0.1 μm. They are required only to have such sizes as will not impair the degree of integration and as will permit necessary energy to be produced, and such dimensions as easy to fabricate.

Also, the surface protective film 6 has been given by a silicon oxide film, but instead may be provided by alumina. Alumina has a high thermal conductivity compared with the silicon oxide film, so that it can make the cooling rate of the buckling member 1 higher and therefore further improve the response characteristic.

Also, the substrate 7, although provided by a silicon (Si) plate in this example, has only to be made of a material whose thermal conductivity is 70 $W \cdot m^{-1} \cdot K^{-1}$ or more. For example, it may be made of a glass plate. In such a case, the surface protective film 6 may be omitted.

Also, the refrigerant to be fed to the refrigerant reservoir 34 is not limited to the ink 15. The refrigerant is required only to be a liquid or sol substance and have a thermal conductivity equal to or more than that of the ink 15.

Further, the ink jet head 90 has been described as one having only one nozzle orifice 11 in this example. However, actually, a plurality of nozzle orifices 11 and the pressure generating member 20 opposed thereto may be arranged on the nozzle plate 10 so that the ink droplet 15a will be discharged through a plurality of places of the nozzle plate 10.

Next described is the method of fabricating the ink jet head 90.

Figs. 15A, 15B, 16A, 16B, ..., 31A, and 31B show the processes of fabricating the pressure generating member 20, which is a main part of the ink jet head 90. A group of Figs. 15A, 16A, 17A, 18A, 19A, 20, 21A, 23A, 24A, 25A, 26A, 27A, 30A, and 31A, and another group of Figs. 15B, 16B, 17B, 18B, 19B, 21B, 22, 23B, 24B, 25B, 26B, 27B, 28B, 29, 30B, and 31B correspond to the cross section taken along the line $X_1 - X_1$ and that taken along the line $Y_1 - Y_1$ in Fig. 3, respectively.

(i) First, as shown in Fig. 15A and 15B, silicon oxide films 6, 6 are formed on the front and rear surfaces of the substrate 7 of both orientations (100) to a specified thickness (e.g., 1 μm) by thermal oxidation.

(ii) Next, as shown in Figs. 16A and 16B, photoresist (not shown) is applied to the rear surface side of the substrate 7, and photolithography is carried out so that a rectangular opening corresponding to the shape of the refrigerant circulation hole 16 (see Fig. 3) is bored in the resist. Then, dry etching is carried out by using CHF_3, whereby a rectangular opening 6a is bored in the thermally oxidized film 6 on the rear surface side. Subsequently, the silicon substrate 7 is immersed in a potassium hydroxide solution, and the substrate 7 is wet-etched from rear surface to front surface side with the thermally oxidized film 6 used as a mask so that the refrigerant circulation hole 16 is formed to a half way. The inner wall surface of the refrigerant circulation hole 16 becomes a (111) plane with a low etching rate. Thereafter, the resist is stripped off. It is noted that the refrigerant circulation hole 16 is formed halfway at this stage because only a slight amount of etching will be required to complete the refrigerant circulation hole 16 in later processes.

(iii) Next, as shown in Figs. 17A and 17B, an aluminum film 120 with a thickness of, for example, 0.5 μm is formed as a first sacrifice layer by, for example, sputtering on the thermally oxidized layer 6 on the front surface side of the substrate. Subsequently, photolithography and etching are carried out on the film so that the aluminum film 120 is processed into a pattern corresponding to the clearance 32 as shown in Fig. 1. Depending on the thickness of the first sacrifice layer, the dimension of the clearance 32 shown in Fig. 1, or the interval A between the surface protective film 6 of the substrate 7 and the first insulating film 2 shown in Fig. 5 is determined.

(iv) Next, as shown in Figs. 18A and 18B, an silicon oxide film 2 with a thickness of, for example, 0.5 μm is formed as a first insulating film on the first sacrifice layer by, for example, sputtering. Subsequently, on the silicon oxide film 2, a tantalum film with a thickness of, for example, 0.01 μm and a nickel film (not shown) with a thickness of, for example, 0.1 μm are formed as the material of the heater layer 3 by, for example, sputtering. Thereafter, photolithography and etching are carried out so that the tantalum film and the nickel film are processed into a pattern. As a result, the heater layer 3 meandered in U-shape is fabricated on the first insulating film 2. It is noted that the tantalum film is formed with a view to increasing the adhesion between the silicon oxide film 2 and the nickel film.

(v) Next, as shown in Figs. 19A and 19B, a silicon oxide film 4 with a thickness of, for example, 0.5 μm is formed as a second insulating film on the heater layer 3. Subsequently, as shown in Fig. 20, photolithography and etching are carried out so that an electrode lead-out hole 160 is formed in the silicon oxide film 4.

(vi) Next, as shown in Figs. 21A and 21B, a tantalum film with a thickness of, for example, 0.01 μm and a nickel film 170 with a thickness of, for example, 0.1 μm are formed as part of the material (a first metal layer) of the buckling member 1 on the silicon oxide film 4 by, for example, sputtering. It is noted that the tantalum film is formed with a view to increasing the adhesion between the silicon oxide film 4 and the nickel film 170.

(vii) Next, as shown in Fig. 22, photoresist 180 is applied on the nickel film 170, and openings corresponding to the pattern of the slits 40 (see Fig. 4) to be formed in the silicon oxide films 2, 4 are formed in the photoresist 180. Subsequently, etching is performed so that the slits 40 are formed in the silicon oxide films 2, 4.

(viii) Next, as shown in Figs. 23A and 23B, photoresist 190 is applied on the photoresist 180 and photolithography is carried out so that the photoresist 190 is left in a configuration corresponding to the pattern of the slits 40. That is, the photoresist 190 is shaped into such a configuration that the slits 40 of the silicon oxide films 2, 4 are buried and that the photoresist 190 is protruded upward from the surface of the silicon oxide film 4 with the same pattern width as the slits 40 to a specified height (a height

exceeding a nickel plated film 200 as described below).

(ix) Next, as shown in Figs. 24A and 24B, a nickel plated film 200 with a specified thickness (for example, 5 µm) is formed as the remaining portion of the material of the buckling member 1 on the silicon oxide film 4 by an electrolytic plating process. As the electrolytic plating process, nickel plating by, for example, nickel sulfamate bathing may be adopted with the nickel film 170 used as an electrode.

In addition, in Fig. 24A, areas sandwiched by the photoresist 190, 190 out of the nickel films 170, 200, and others form the buckling member 1, while areas outer than the photoresist 190, 190 out of the nickel films 170, 200, and others form wirings 51a, 51b as shown in Fig. 1.

(x) Next, as shown in Figs. 25A and 25B, an aluminum film 210 with a thickness of, for example, 0.5 µm is formed on the nickel plated film 200 as a second sacrifice layer by, for example, sputtering. Subsequently, photolithography is performed and etching with a potassium hydroxide solution used as the etchant is performed, so that the aluminum film 210 is processed into a pattern corresponding to the clearance 33 as shown in Fig. 1. Depending on the thickness of the second sacrifice layer 210, the size of the clearance 33 shown in Fig. 1, or the interval D between the buckling member 1 and the diaphragm 5 shown in Fig. 5 is determined.

In addition, since the etching of the second sacrifice layer 210 is performed by using an alkaline etchant (potassium hydroxide solution), the resist 190 present outside the pattern of the second sacrifice layer 210 (see Fig. 24A) is removed together with the second sacrifice layer 210. Meanwhile, the photoresist 190 present inside the pattern of the second sacrifice layer 210 is left as it is under the second sacrifice layer 210, as shown in Fig. 25B.

(xi) Next, as shown in Fig. 26A and 26B, on the second sacrifice layer 210, a tantalum film with a thickness of, for example, 0.01 µm and a nickel film (not shown) with a thickness of, for example, 0.1 µm are formed as part of the material of the diaphragm 5 (a second metal layer) by, for example, sputtering. Subsequently, a nickel plated film 220 with a specified thickness (for example, 4 µm) is formed thereon as the remaining portion of the material of the diaphragm 5 with the nickel film used as an electrode by an electrolytic plating process. As the electrolytic plating process, nickel plating by, for example, nickel sulfamate bathing may be adopted with the nickel film 170 used as an electrode. In addition, the tantalum film is formed with a view to increasing the adhesion between the nickel film 200 or the aluminum film 210 and the nickel film formed in this step.

(xii) Next, as shown in Figs. 27A and 27B, the substrat 7 in this state is immersed in a potassium hydroxide solution, and the silicon substrate 7 is etched by using as masks the nickel plated film 220 on the front surface side of the substrate and the thermally oxidized film 6 on the rear surface side of the substrate. By this process, the refrigerant circulation hole 16 is completed so as to be bored through from the rear to the front surface side of the substrate 7. The inner peripheral surface of the refrigerant circulation hole 16 becomes a (111) plane with a low etching rate. The etching is stopped at the surface protective film 6 of the substrate 7.

(xiii) Next, as shown in Figs. 28A and 28B, the substrate 7 in this state is immersed in a hydrofluoric acid solution, and the thermally oxidized film 6 on the rear surface side of the substrate and the aluminum film 120 as the first sacrifice layer are etched and thereby removed. By this process, the clearance 32 is formed between the surface protective film 6 of the substrate 7 and the first insulating film 2. Subsequently, as shown in Fig. 29, the substrate 7 is immersed in the aforementioned potassium hydroxide solution, and the photoresist 190 and the aluminum film 210 as the second sacrifice layer are etched and thereby removed. As a result, the clearance 33 is formed between the buckling member 1 and the diaphragm 5.

(xiv) Next, as shown in Figs. 30A and 30B, photoresist 230 is applied to the front surface side of the substrate, and photolithography and chart are carried out so that the diaphragm 5 is formed by patterning the nickel film 220 and the like.

(xv) Next, as shown in Figs. 31A and 31B, the photoresist 230 is stripped off. As a result, the counter 20 is completed.

(xvi) Finally, as shown in Fig. 1, the nozzle plate 10 is installed via the spacer 8 on the front surface side of the substrate 7 in this state, and besides the housing 9 is joined on the rear surface side of the substrate 7, whereby the ink jet head 90 is completed. It is assumed that the ink feed passage 14 in the spacer 8, the nozzle orifice 11 in the nozzle plate 10, and the refrigerant feed passage 35 in the housing 9 are previously fabricated.

As seen above, in this fabricating method, since the pressure generating member 20 is fabricated by semiconductor integrating processes, the ink jet head 90 can be fabricated into small size. Also, since the two clearances 32, 33 in the pressure generating member 20 are formed collectively and continuously, the fabricating process can be simplified. Yet, since the clearances 32, 33 are formed according to the thicknesses of the first sacrifice layer 120 and the second sacrifice layer 210, the dimension of the clearances 32, 33, or the interval A between the surface protective film 6 of the substrate 7 and the first insulating film 2, as well as the interval D between the buckling member 1 and the diaphragm 5 can be set each with a high accuracy. For example, the interval A can be set to 0.1 µm or less and the interval D can be set to 1.0 µm or more. As a result, the response

speed of the ink jet head 90 can be improved so that high-speed printing can be realized.

As apparent from the foregoing description, in the ink jet head of the present invention, since the substrate is present on the rear side, heat of the pressure generating member, especially of the buckling member and the heater layer, can be discharged out of the ink chamber rapidly through the substrate, by selecting a material having a thermal conductivity larger than that of ink by one order or more as the material of the substrate. Accordingly, the cooling rate of the pressure generating member can be made high and, as a result, a good response characteristic is obtained so that high-speed printing becomes possible. Also, since the buckling member and the heater layer, which constitute the pressure generating member, are provided by independent layers, the heater layer may be shaped into a narrow pattern irrespectively of the shape of the buckling member. Such an arrangement saves the amount of current for energization involved in obtaining a required amount of heat so that the power consumption can be reduced.

In the ink jet head of the present invention, since the substrate is present on the rear side of the pressure generating member, heat of the pressure generating member, especially of the buckling member, can be discharged out of the ink chamber rapidly through the substrate, by selecting a material having a thermal conductivity larger than that of ink by one order or more as the material of the substrate. Accordingly, the cooling rate of the pressure generating member can be made high and, as a result, a good response characteristic is obtained so that high-speed printing becomes possible. Also, thanks to the diaphragm, the ink present in a clearance between the nozzle plate and the pressure generating member (diaphragm) can be prevented from going around to the rear side of the pressure generating member (diaphragm) during an operation. As a result, the discharge force and discharge rate of ink can be made large. Further, since the buckling member and the diaphragm, which constitute the pressure generating member, are provided separately, the buckling member may be shaped irrespectively of the shape of the diaphragm. For example, it becomes possible to form slits in the buckling member. Such an arrangement allows the buckling member to be rapidly cooled by circulating the refrigerant such as ink through the buckling member on the rear side of the diaphragm. As a result, an even better response characteristic can be obtained so that high-speed printing becomes possible.

In the ink jet head of one embodiment, since the substrate is present on the rear side of the pressure generating member, heat of the pressure generating member, especially of the buckling member and the heater layer, can be discharged out of the ink chamber rapidly through the substrate, by selecting a material having a thermal conductivity larger than that of ink by one order or more as the material of the substrate. Accordingly, the cooling rate of the pressure generating member can be made high and, as a result, a good response characteristic can be obtained so that high-speed printing becomes possible. Also, since the buckling member and the heater layer, which constitute the pressure generating member, are provided by independent layers, the heater layer may be shaped into a narrow pattern irrespectively of the shape of the buckling member. Such an arrangement saves the amount of current for energization involved in obtaining a required amount of heat so that the power consumption can be reduced. Further, thanks to the diaphragm, the ink present in a clearance between the nozzle plate and the pressure generating member (diaphragm) can be prevented from going around to the rear side of the pressure generating member (diaphragm) during an operation. As a result, the discharge force and discharge rate of ink can be made large. Further, since the buckling member and the diaphragm, which constitute the pressure generating member, are provided separately, the buckling member may be shaped irrespectively of the shape of the diaphragm. For example, it becomes possible to form slits in the buckling member. Such an arrangement allows the buckling member and the heater layer to be rapidly cooled by circulating the refrigerant such as ink through the buckling member on the rear side of the diaphragm. As a result, an even better response characteristic can be obtained so that high-speed printing becomes possible.

In the ink jet head of one embodiment, since the heater layer is provided along the rear surface of the buckling member out of both surfaces of the buckling member, the heater layer that has been heated to a high temperature particularly out of the pressure generating member can be rapidly cooled through the substrate. Accordingly, the cooling rate of the pressure generating member can be made even higher and, as a result, an even better response characteristic can be obtained so that high-speed printing becomes possible.

In the ink jet head of one embodiment, since the pressure generating member has a first insulating layer provided between the substrate and the heater layer, the substrate and the heater layer can be successfully insulated from each other so that the current flowing through the heater layer can be prevented from leaking to the substrate. As a result, the amount of current required to obtain the necessary heat generation can be saved so that the power consumption can be reduced.

In the ink jet head of one embodiment, since the pressure generating member has a second insulating layer provided between the buckling member and the heater layer, the buckling member and the heater layer can be successfully insulated from each other so that the current flowing through the heater layer can be prevented from leaking to the buckling member. As a result, the amount or current required to obtain the necessary heat generation can be saved so that the power consumption can be reduced.

In the ink jet head of one embodiment, since the diaphragm is formed into a generally disc shape, the volumetric variation of the ink chamber (a clearance between the nozzle plate and the pressure generating member)

can be made large for a small surface area of the diaphragm. Accordingly, the discharge force and discharge rate can be made large for the small surface area of the diaphragm. Conversely, when the discharge force of ink is larger than necessary, the ink jet head may be miniaturized by reducing the diameter of the diaphragm.

In the ink jet head of one embodiment, at least part of the diaphragm other than the peripheral portion is coupled to the buckling member. Therefore, when the buckling member is going to restore to the original position after a heating period and upon the entrance into a cooling period, the diaphragm undergoes a tensile force from the buckling member in addition to its own restoring force. As a result of this, the diaphragm restores to the original position faster. Accordingly, the response characteristic of the pressure generating member can be improved so that high-speed printing is enabled.

In the ink jet head of one embodiment, the center portion of the diaphragm is coupled to the center portion of the buckling member. Therefore, a portion (center portion) that has been displaced to the most extent out of the diaphragm during a heating period is pulled by a portion (center portion) that restores fastest out of the buckling member upon the entrance into a cooling period. As a result, the diaphragm restores to the original position even faster. Accordingly, the response characteristic of the pressure generating member can be improved so that high-speed printing is enabled.

In the ink jet head of one embodiment, a clearance is provided between an intermediate portion between the peripheral portion and the part coupled to the buckling member out of the diaphragm, and the buckling member. Therefore, it becomes possible to rapidly cool the buckling member by circulating the refrigerant such as ink through the clearance between the diaphragm and the buckling member, on the rear side of the diaphragm. As a result, an even better response characteristic can be obtained so that high-speed printing is enabled.

In the ink jet head of one embodiment, a clearance is provided between a portion of the buckling member inner than its peripheral portion out of the pressure generating member, and the substrate. Therefore, it becomes possible to rapidly cool the buckling member and the heater layer by circulating the refrigerant such as ink through the clearance between the buckling ember and the substrate, on the rear side of the diaphragm. As a result, an even better response characteristic can be obtained so that high-speed printing is enabled.

In the ink jet head of one embodiment, the distance between the substrate and the aforementioned portion of the pressure generating member is set to within a range of 0.05 μm to 2.0 μm. Therefore, the clearance between the substrate and the pressure generating member can be easily formed, and also the response characteristic of the pressure generating member can be maintained good. That is, if the dimension of the clearance is 0.05 μm or more, the clearance can be formed by stacking the material of the sacrifice layer (a layer for processing) and that of the pressure generating member on the substrate one by one, and by removing the sacrifice layer with an etchant. Further, if the dimension of the clearance is 2.0 μm or less, heat of the pressure generating member, especially of the buckling member and the heater layer, can be discharged rapidly out of the ink chamber through the substrate during a cooling period.

In the ink jet head of one embodiment, a slit is provided at a portion of the pressure generating member inner than the peripheral portion of the buckling member, so as to be bored through from the surface opposite to the substrate to the diaphragm side surface of the buckling member. Therefore, the buckling member can be rapidly cooled by circulating the refrigerant such as ink through the slit on the rear side of the diaphragm. In particular, when clearances are provided between the diaphragm and the buckling member and between the substrate and the pressure generating member, these clearances communicate with each other through the slit so that the cooling effect can be enhanced. As a result, the response characteristic is further improved so that high-speed printing is enabled.

In the ink jet head of one embodiment, a plurality of slits as described above are provided, and it is arranged that a strip-shaped portion of the buckling member sandwiched by the slits will be buckled. Therefore, for example, by attaching the entire peripheral portion of the buckling member to the substrate, thermal stress of the buckling portion due to repeated heating and cooling can be received by the entire peripheral portion. Accordingly, the thermal stress of the buckling portion is not applied only to particular portions, but can be relaxed and received by the entire peripheral portion. As a result, the place where the substrate and the buckling member are fitted to each other can be prevented from being damaged, so that the ink jet head can be prolonged in its service life.

In the ink jet head of one embodiment, the substrate is provided with a refrigerant circulation hole which is bored through the substrate and which confronts a portion of the pressure generating member inner than the peripheral portion of the buckling member. Therefore, the refrigerant such as ink can be fed from the rear side of the substrate to the front side of the substrate through the refrigerant circulation hole. The fed refrigerant circulates between the front and rear sides of the substrate as the pressure generating member is displaced and restored by heating and cooling. Accordingly, it becomes possible to rapidly cool the pressure generating member. This fact is particularly significant when the ink is prevented from going around to the rear side of the diaphragm by the diaphragm being provided. Also, when a clearance is provided between the diaphragm and the buckling member or between the substrate and the pressure generating member, or when slits bored through from the surface opposite to the substrate to the diaphragm-side surface of the buckling member are provided at portions of the pressure generating member inner than the periph ral portion of the buckling member, the refrigerant circulates through the clearances or slits

so that the cooling effect can be enhanced. As a result, an even better response characteristic can be obtained so that high-speed printing is enabled.

In the ink jet head of one embodiment, the refrigerant circulation hole is so arranged that its size gradually decreases from the rear side toward the front side of the substrate. Therefore, the opposing area between the pressure generating member and the substrate surface is less reduced as compared to when the refrigerant circulation hole is not provided. Accordingly, heat of the pressure generating member, especially heat of the buckling member and the heater layer, can be discharged rapidly out of the ink chamber through the substrate. As a result, the cooling rate of the pressure generating member can be maintained high, so that the response characteristic can be maintained good.

In the ink jet head of one embodiment, a refrigerant reservoir communicating with the refrigerant circulation hole is formed on the rear side of the substrate. Therefore, the refrigerant such as ink can be fed to the front side of the substrate from the refrigerant reservoir through the refrigerant circulation hole.

According to the method for fabricating the ink jet head in one embodiment, since the pressure generating member can be fabricated by semiconductor integrating processes, the ink jet head can be fabricated into small size. Further, two clearances, i.e., one clearance between the substrate and the pressure generating member and the other clearance between the buckling member and the diaphragm in the pressure generating member, can be collectively fabricated by etching and removing continuously the first sacrifice layer and the second sacrifice layer. Accordingly, the fabrication processes can be simplified. Yet, the two clearances are formed in response to the thicknesses of the first sacrifice layer and the second sacrifice layer, respectively, so that the distances of the clearances can be set with high accuracy.

The invention being thus described, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.

Claims

1. An ink jet head which comprises: an ink chamber (31) including as part of its peripheral wall a nozzle plate (10) having a nozzle opening (11), and a substrate (7) opposed to the nozzle plate (10); and a pressure generating member (20) provided in the ink chamber (31) and opposed to the nozzle plate (10), wherein the pressure generating member (20) is deformed to generate a pressure within the ink chamber (31), so that ink liquid in the ink chamber (31) is discharged out of the ink chamber (31) through the nozzle opening (11),

    the pressure generating member (20) comprising:

    a buckling member (1) which is formed into a generally plate shape, where portions forming both ends in at least one direction out of a peripheral portion of the buckling member (1) are attached to the substrate (7), and which buckling member (1) is switchable between a no-displacement state in which the buckling member (1) undergoes substantially no thermal stress, and a buckling state in which the buckling member (1) is buckled through thermal expansion; and

    a heater layer (3) which is provided along one surface of the buckling member (1) and which generates heat through electrical energization.

2. An ink jet head which comprises: an ink chamber (31) including as part of its peripheral wall a nozzle plate (10) having a nozzle opening (11), and a substrate (7) opposed to the nozzle plate (10); and a pressure generating member (20) provided in the ink chamber (31) and opposed to the nozzle plate (10), wherein the pressure generating member (20) is deformed to generate a pressure within the ink chamber (31), so that ink liquid in the ink chamber (31) is discharged out of the ink chamber (31) through the nozzle opening (11),

    the pressure generating member (20) comprising:

    a buckling member (1) which is formed into a generally plate shape, where portions forming both ends in at least one direction out of a peripheral portion of the buckling member are attached to the substrate (7), and which buckling member (1) is switchable between a no-displacement state in which the buckling member (1) undergoes substantially no thermal stress, and a buckling state in which the buckling member (1) is buckled through thermal expansion; and

    a diaphragm (5) which is composed of a generally plate-shaped flexible material, and which is provided along one surface of the buckling member (1) on the nozzle plate (10) side out of both surfaces of the buckling member (1) in such a state that a peripheral portion (5c) of the diaphragm (5) is attached to the peripheral portion (1c) of the buckling member (1).

3. The ink jet head as claimed in Claim 1, wherein

    the pressure generating member (20) further comprises:

    a diaphragm (5) which is composed of a generally plate-shaped flexible material, and which is provided along one surface of the buckling member (1) on the nozzle plate (10) side out of both surfaces of the buckling member (1) in such a state that a peripheral portion (5c) of the diaphragm (5) is attached to the peripheral portion (1c) of the buckling member (1).

4. The ink jet head as claimed in Claim 1, wherein the heater layer (3) is provided along one surface of the buckling member (1) on the substrate (7) side out of both surfaces of the buckling member (1).

5. The ink jet head as claimed in Claim 1, wherein the pressure generating member (20) has a first insulating layer (2) provided between the substrate (7) and the heater layer (3).

6. The ink jet head as claimed in Claim 1, wherein the pressure generating member (20) has a second insulating layer (4) provided between the buckling member (1) and the heater layer (3).

7. The ink jet head as claimed in Claim 2, wherein the diaphragm (5) is formed into a generally disc shape.

8. The ink jet head as claimed in Claim 2, wherein in addition to the peripheral portion of the diaphragm (5), at least one part (5a) of the diaphragm (5) other than the peripheral portion (5c) is coupled to the buckling member (1).

9. The ink jet head as claimed in Claim 2, wherein a center portion (5a) of the diaphragm (5) is coupled to a center portion (1a) of the buckling member (1).

10. The ink jet head as claimed in Claim 9, wherein a clearance (33) is provided between an intermediate portion between the peripheral portion (5c) and the center portion (5a) of the diaphragm (5), and the buckling member (1).

11. The ink jet head as claimed in Claim 1, wherein a clearance (32) is provided between a portion of the pressure generating member (20) present inner than the peripheral portion (1c) of the buckling member (1), and the substrate (7).

12. The ink jet head as claimed in Claim 2, wherein a clearance (32) is provided between a portion of the pressure generating member (20) present inner than the peripheral portion (1c) of the buckling member (1), and the substrate (7).

13. The ink jet head as claimed in Claim 11, wherein a distance between the substrate (7) and the above-defined portion of the pressure generating member (20) is set within a range of 0.05 μm to 2.0 μm.

14. The ink jet head as claimed in Claim 12, wherein a distaste between the substrate (7) and the above-defined portion of the pressure generating member (20) is set within a range of 0.05 μm to 2.0 μm.

15. The ink jet head as claimed in Claim 1, wherein at least one slit (40) is provided at a portion of the pressure generating member (20) present inner than the peripheral portion (1c) of the buckling member (1) so as to be bored through from a surface opposed to the substrate (7) to a surface of the buckling member (1) on the nozzle plate (10) side.

16. The ink jet head as claimed in Claim 2, wherein at least one slit (40) is provided at a portion of the pressure generating member (20) present inner than the peripheral portion (1c) of the buckling member (1) so as to be bored through from a surface opposite to the substrate (7) to a surface of the buckling member (1) on the nozzle plate (10) side.

17. The ink jet head as claimed in Claim 15, wherein a plurality of the slits (40) are provided, and a strip-shaped portion (1b) of the buckling member (1) sandwiched by the slits (40) is so arranged as to be buckled.

18. The ink jet head as claimed in Claim 16, wherein a plurality of the slits (40) are provided, and a strip-shaped portion (1b) of the buckling member (1) sandwiched by the slits (40) is so arranged as to be buckled.

19. The ink jet head as claimed in Claim 1, wherein a refrigerant circulation hole (16) is provided in the substrate (7) so as to be bored through the substrate (7) and confront a portion of the pressure generating member (20) present inner than the peripheral portion (1c) of the buckling member (1).

20. The ink jet head as claimed in Claim 2, wherein a refrigerant circulation hole (16) is provided in the substrate (7) so as to be bored through the substrate (7) and confront a portion of the pressure generating member (20) present inner than the peripheral portion (1c) of the buckling member (1).

21. The ink jet head as claimed in Claim 19, wherein the refrigerant circulation hole (16) is so formed that a size of the refrigerant circulation hole (16) gradually decreases from one side of the substrate (7) opposite to the side on which the pressure generating member (20) is provided, toward the pressure generating member (20) side of the substrate (7).

22. The ink jet head as claimed in Claim 20, wherein the refrigerant circulation hole (16) is so formed that a size of the refrigerant circulation hole (16) gradually decreases from one side of the substrate (7) opposite to the side on which the pressure generating member (20) is provided, toward the pressure generating member (20) side of the substrate (7).

23. The ink jet head as claimed in Claim 19, wherein a refrigerant reservoir (34) communicating with the refrigerant circulation hole (16) is provided on one side of the substrate (7) opposite to the side on which the pressure generating member (20) is provided.

24. The ink jet head as claimed in Claim 20, wherein a refrigerant reservoir (34) communicating with the refrigerant circulation hole (16) is provided on one side of the substrate (7) opposite to the side on which the pressure generating member (20) is provided.

25. A method for fabricating an ink jet head which comprises: an ink chamber (31) including as part of its peripheral wall a nozzle plate (10) having a nozzle opening (11), and a substrate (7) opposed to the nozzle plate (10); and a pressure generating member (20) provided in the ink chamber (31) and opposed to the nozzle plate (10), wherein the pressure generating member (20) comprises a plate-shaped buckling member (1), a heater layer (3) provided on one side of the buckling member (1) on which the substrate (7) is provided, and a diaphragm (5) provided on one side of the buckling member (1) on which the nozzle plate (10) is provided, the method comprising the steps of:

forming a first sacrifice layer (120) having a pattern occupying a specified closed area on a surface of the substrate (7);

forming a first insulating layer (2) composed of a material that can be etched selectively with the first sacrifice layer (120) in such a manner that the first insulating layer (2) covers the first sacrifice layer (120);

forming on the first insulating layer (2) a heater layer (3) having a pattern passing through an area occupied by the first sacrifice layer (120);

forming a second insulating layer (4) composed of a material that can be etched selectively with the first sacrifice layer (120) in such a manner that the second insulating layer (4) covers the above-formed layers (2, 3);

forming slits (40) along both sides of the pattern of the heater layer (3) in such a manner that the slits (40) extend from a front surface of the second insulating layer (4) to a front surface of the first sacrifice layer (120);

burying interiors of the slits (40) by applying resist onto the substrate (7) and by performing photolithography, and forming a resist wall (190) that protrudes from the front surface of the second insulating layer (4) by a specified height with its width kept equal to that of the slits (40);

forming on the second insulating layer (4) a first metal layer (200) for constituting the buckling member (1), by a plating process into a specified thickness which does not exceed the height of the resist wall (190);

forming a second sacrifice layer (210) composed of a material that can be etched selectively with the first metal layer (200), on a closed area generally corresponding to the first sacrifice layer (120) in such a manner that the second sacrifice layer (210) covers a specified portion of a front surface of the first metal layer (200) as well as the slits (40);

forming a second metal layer (220) serving for constituting the diaphragm (5) and composed of a material that can be etched selectively with the second sacrifice layer (210), all over so that the second metal layer (220) covers the above-formed layers (200, 210) on the surface of the substrate (7);

boring a hole (16) reaching the first sacrifice layer (120) on the front surface side of the substrate (7) by performing etching from a rear surface side of the substrate (7), etching and thereby removing the first sacrifice layer (120) through the hole (16) selectively with the first and second insulating layers (2, 4), and subsequently removing the resist wall (190), and further etching and thereby removing the second sacrifice layer (210) through the slits (40) generated by removing the resist wall (190) selectively with the first and second metal layers (200, 220); and

forming the diaphragm (5) having a specified configuration by patterning the second metal layer (220).

Fig. 1

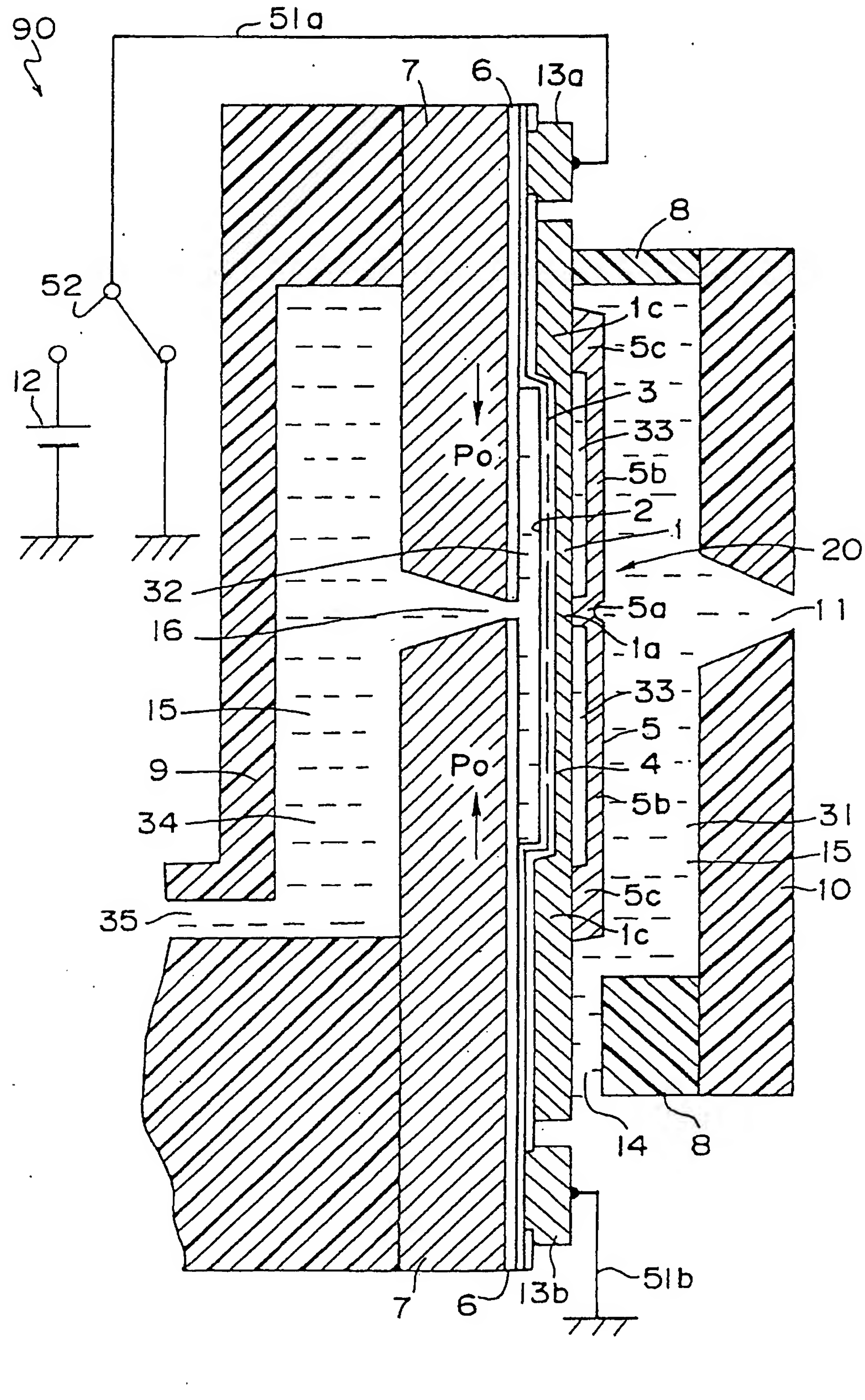

90
51a
7
6
13a
8
52
1c
5c
12
3
33
Po
5b
2
1
20
32
5a
11
16
1a
33
15
5
9
Po
4
5b
34
31
15
5c
10
35
1c
14
8
7
6
13b
51b

Fig. 2

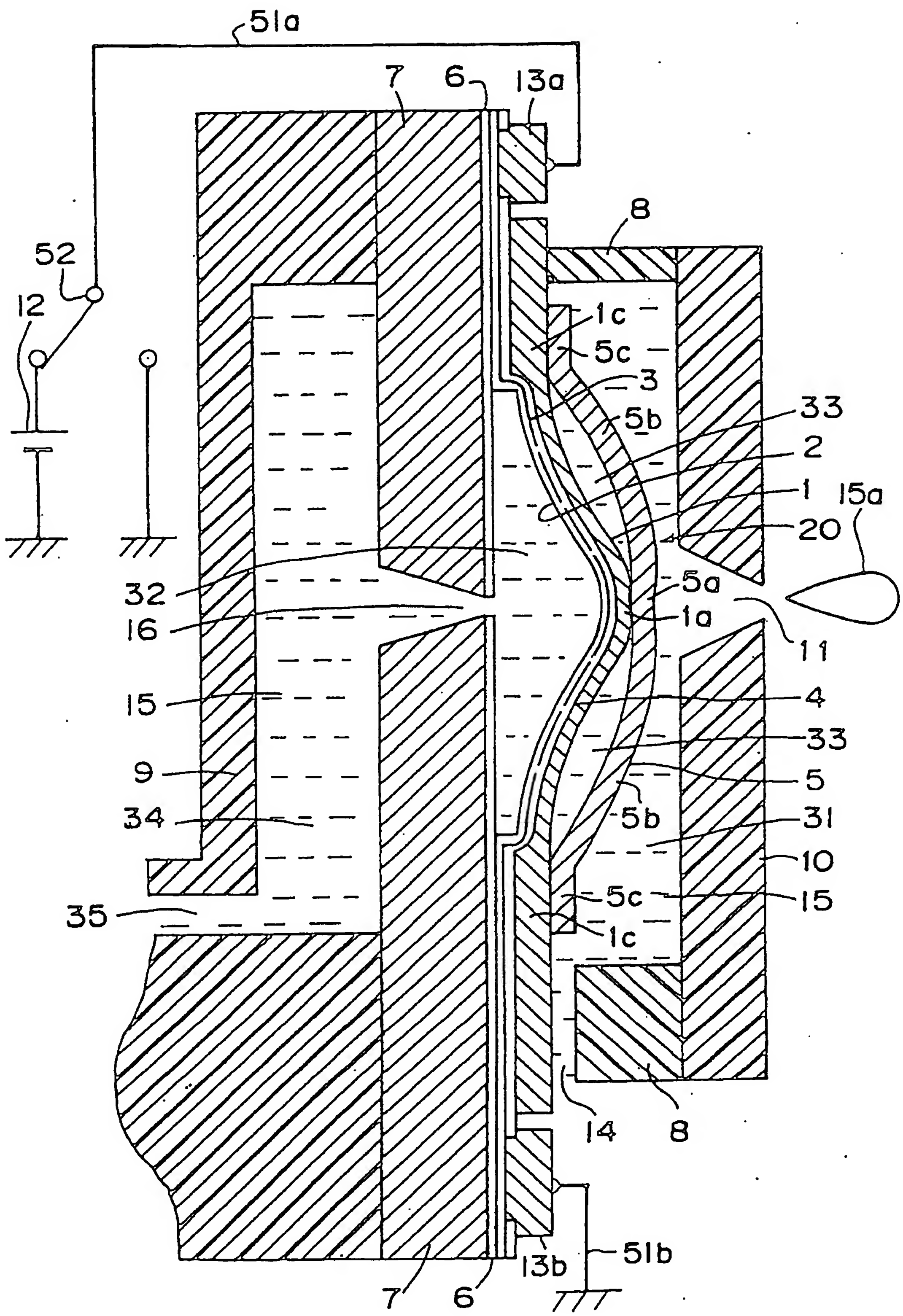

51a
7
6
13a
8
52
12
1c
5c
3
5b
33
2
1
15a
20
32
5a
16
1a
11
15
4
33
9
5
34
5b
31
10
35
5c
15
1c
14
8
13b
51b
7
6

Fig. 3

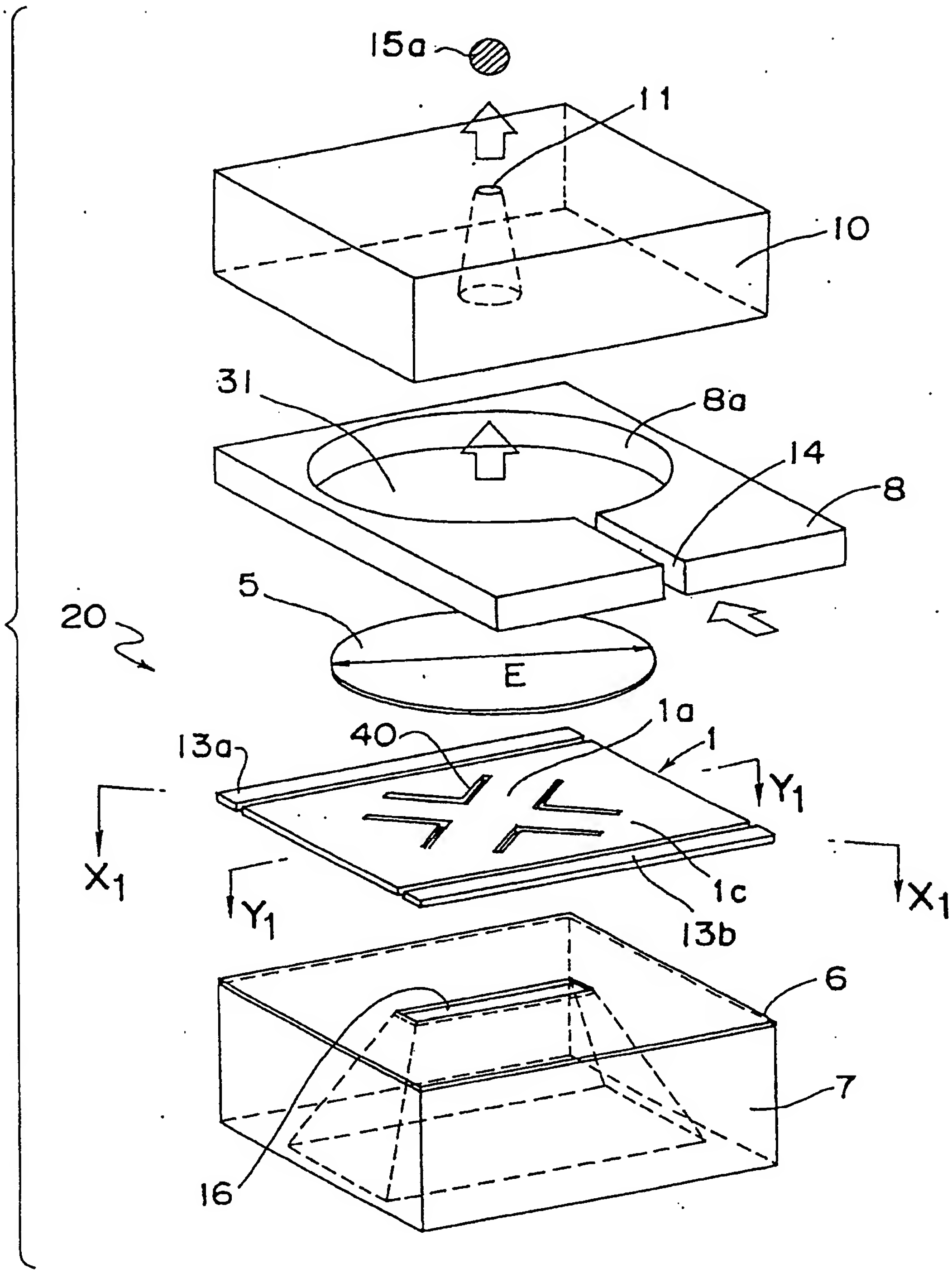
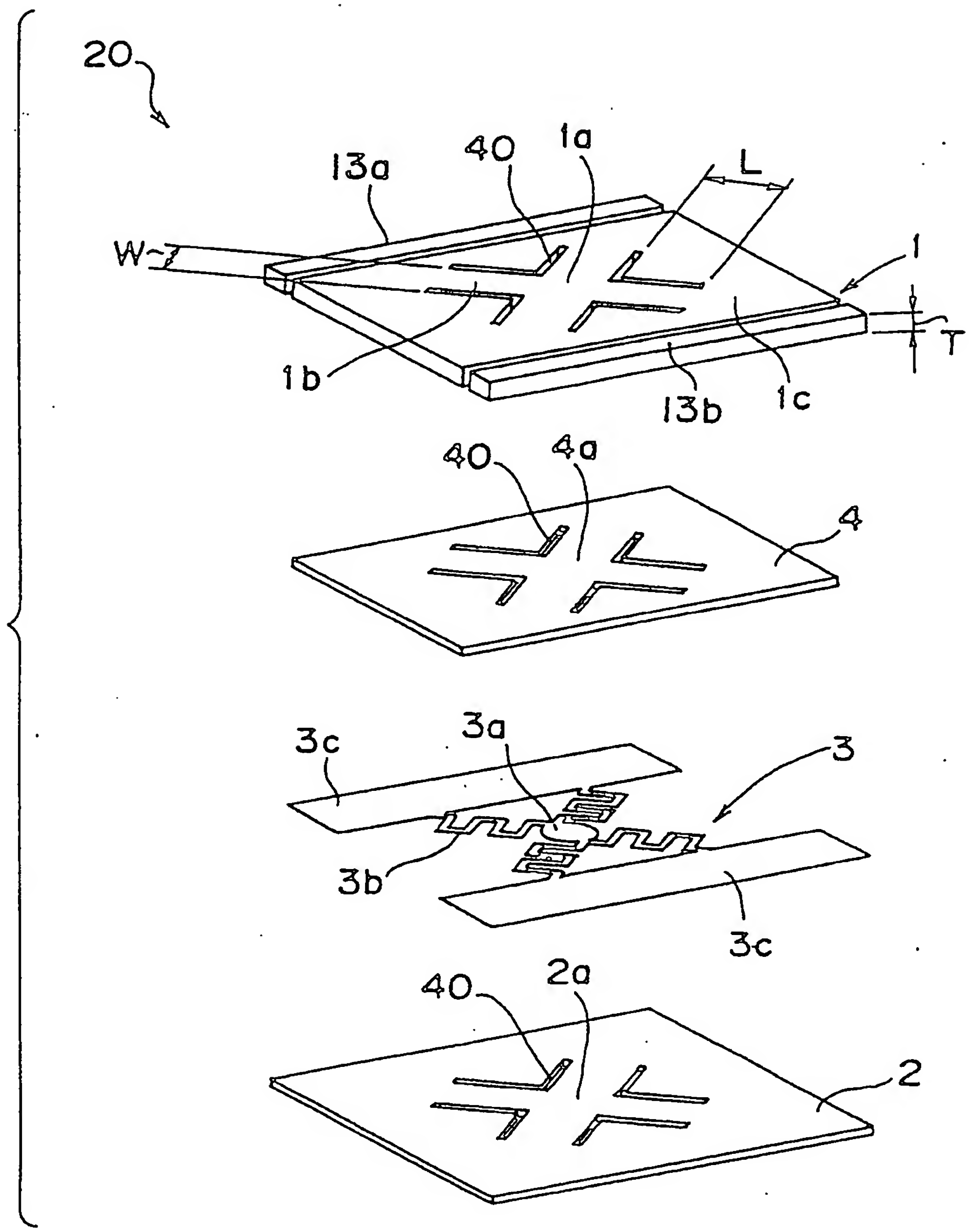


Fig. 4



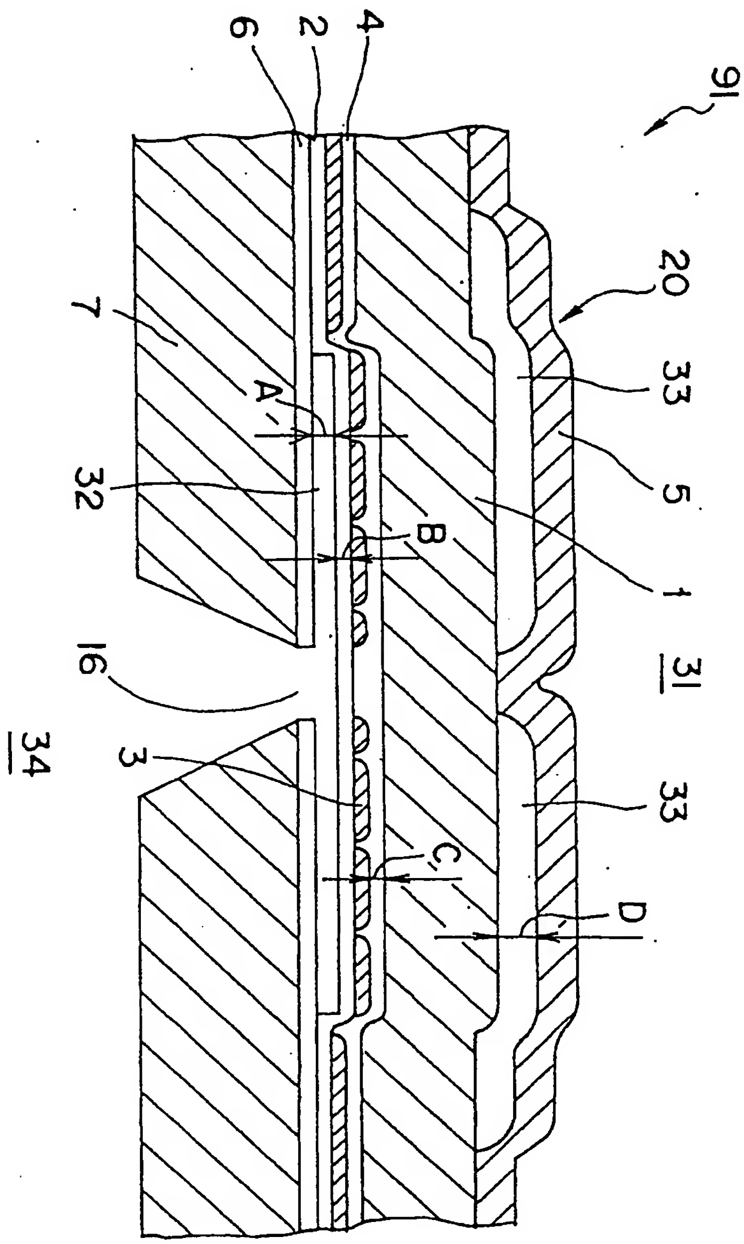


Fig. 5

Fig. 6

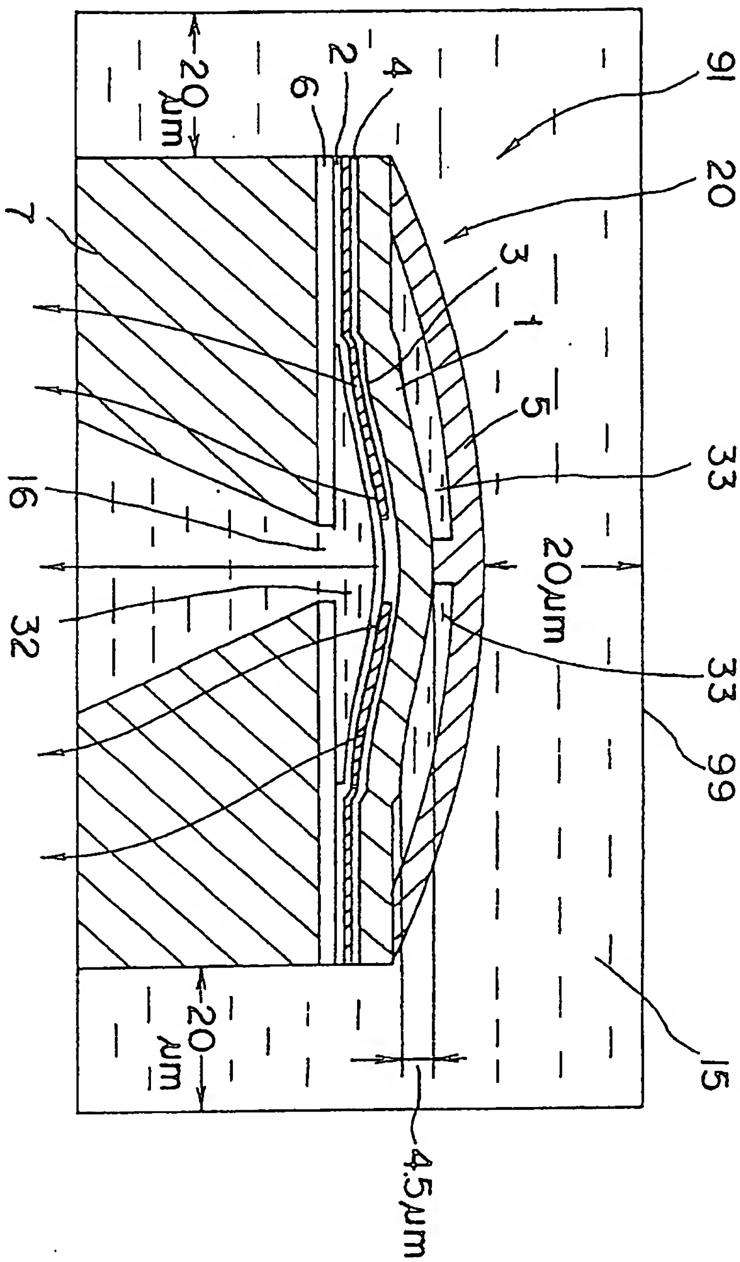


Fig.7A

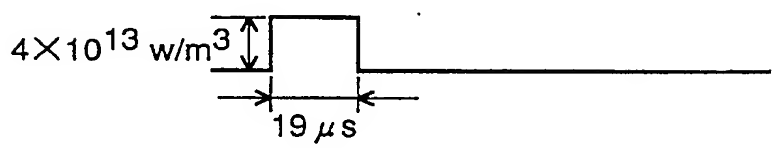

4×10^13 w/m^3
19 μs

Fig.7B

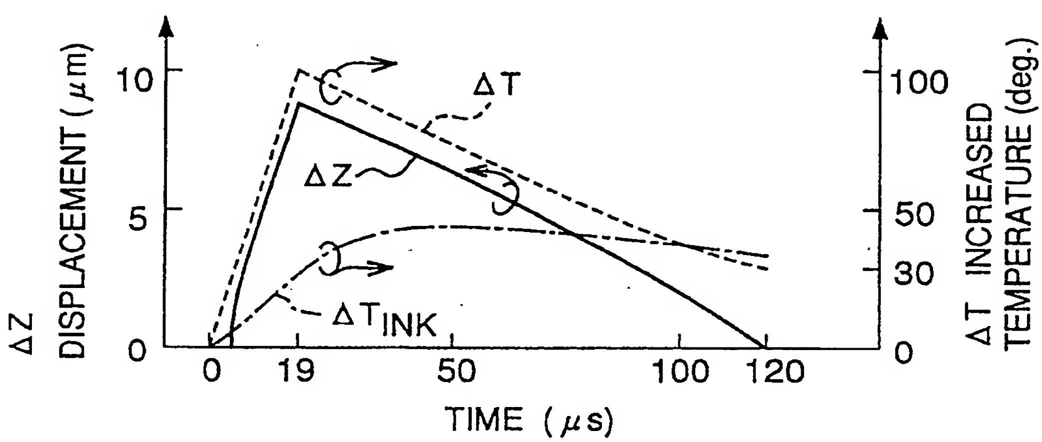

ΔZ DISPLACEMENT (μm)
10
5
0
ΔT
ΔZ
ΔT INK
0
19
50
100
120
TIME (μs)
100
50
30
0
ΔT INCREASED TEMPERATURE (deg.)

Fig.8A

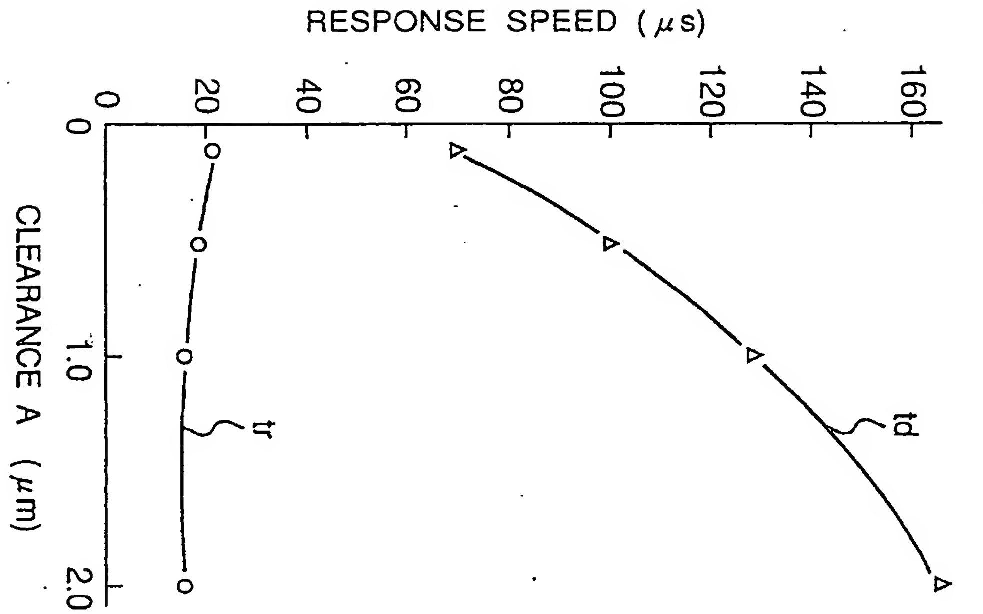
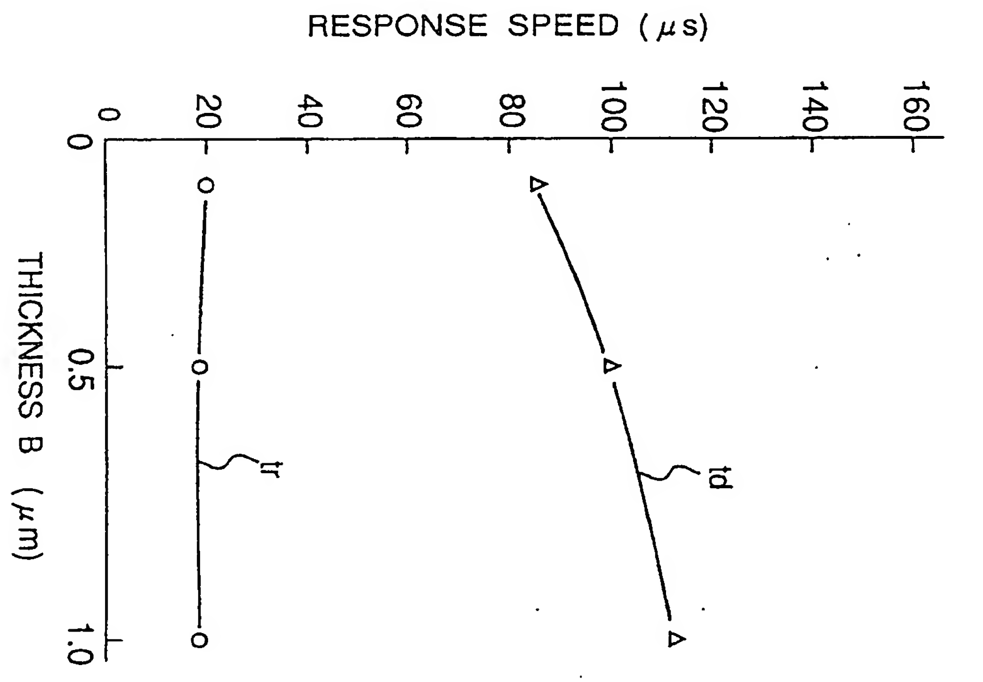

RESPONSE SPEED (μs)
0
20
40
60
80
100
120
140
160
0
1.0
2.0
CLEARANCE A (μm)
td
tr

Fig.8B


RESPONSE SPEED (μs)
0
20
40
60
80
100
120
140
160
0
0.5
1.0
THICKNESS B (μm)
td
tr

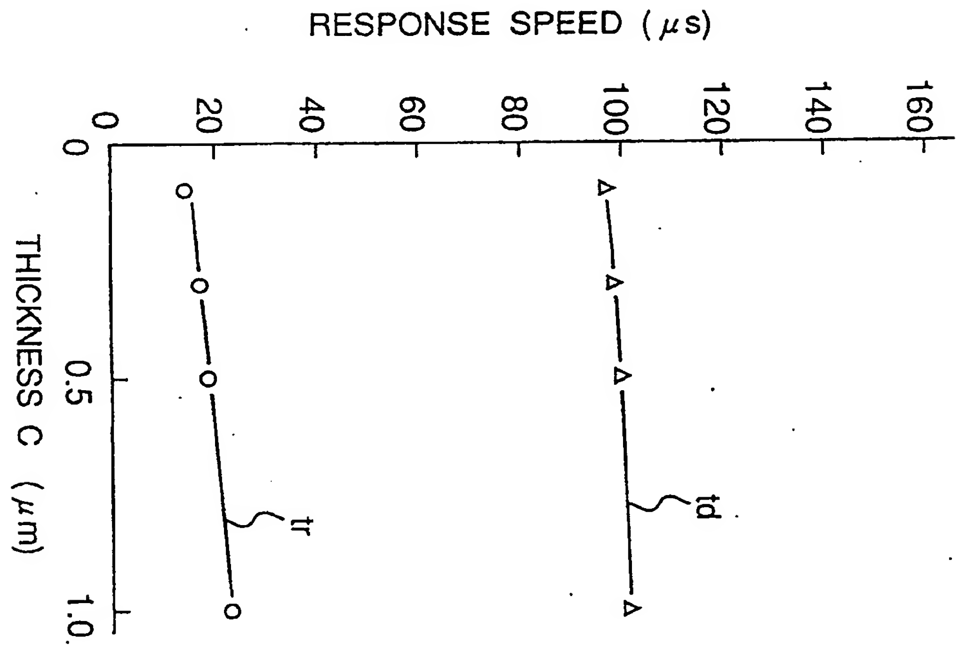

RESPONSE SPEED (μs)
0
20
40
60
80
100
120
140
160
0
0.5
1.0
THICKNESS C (μm)
td
tr

Fig.9A

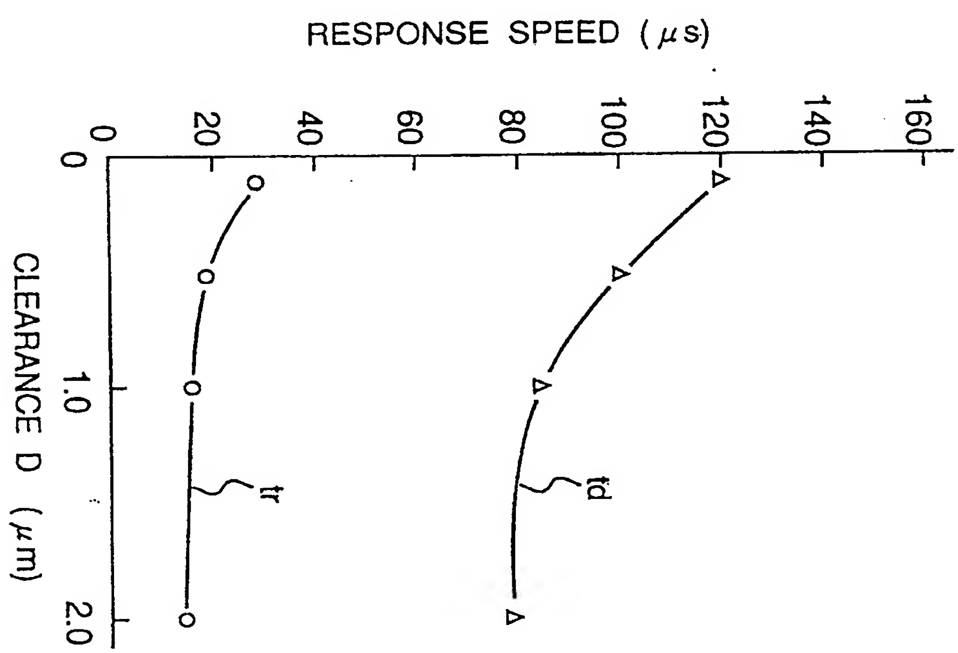

RESPONSE SPEED (μs)
0
20
40
60
80
100
120
140
160
0
1.0
2.0
CLEARANCE D (μm)
td
tr

Fig.9B

Fig. 10

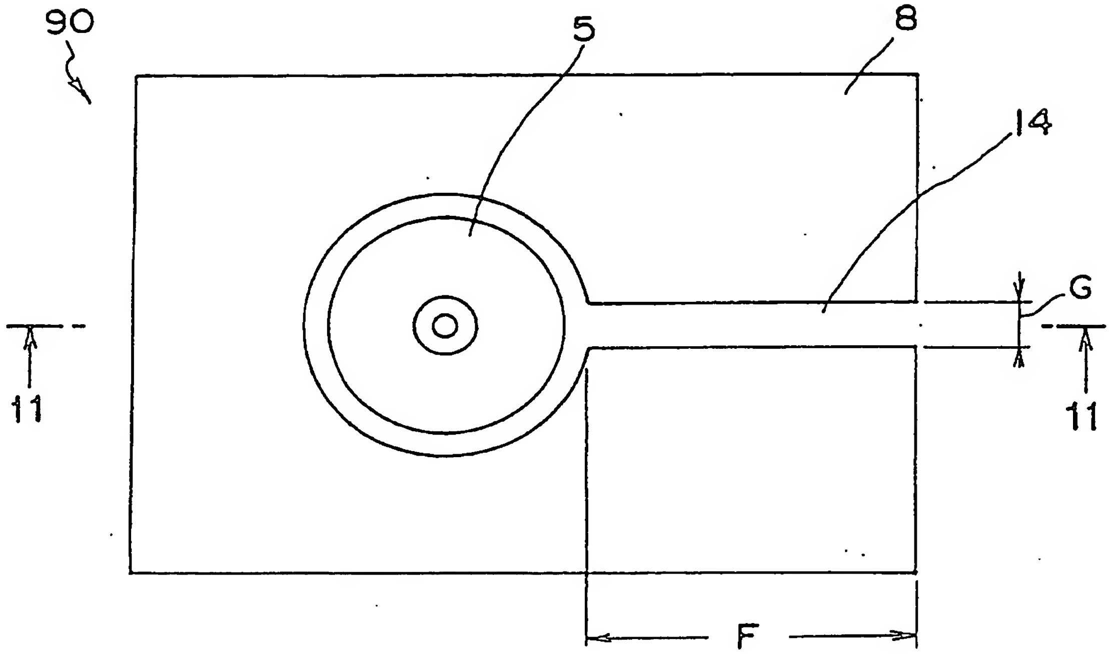


Fig. 11

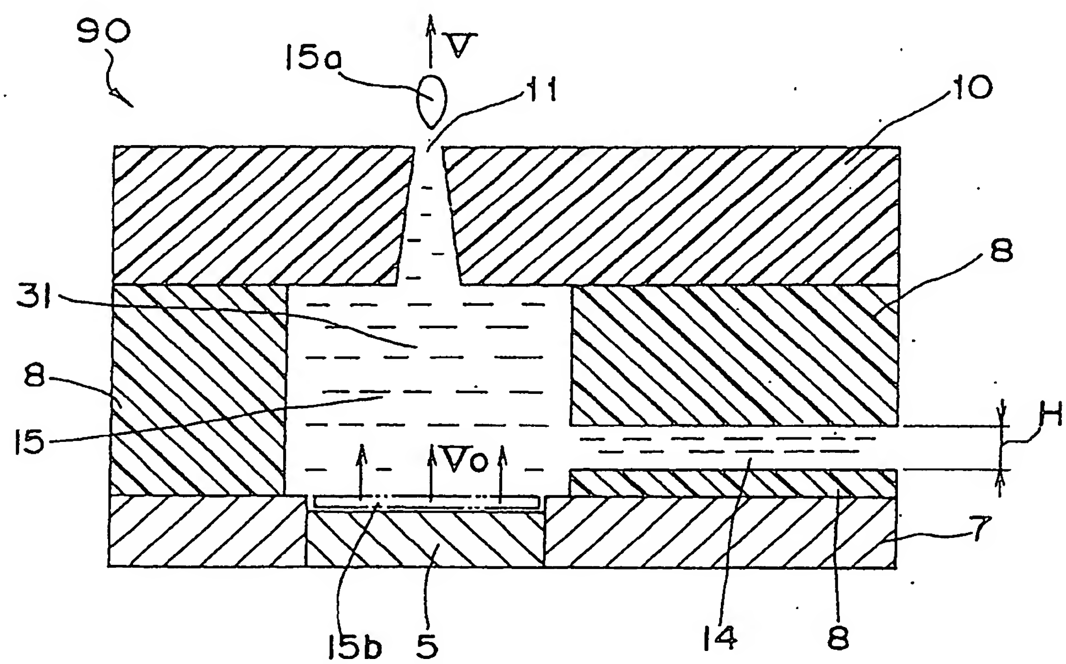


Fig. 12A

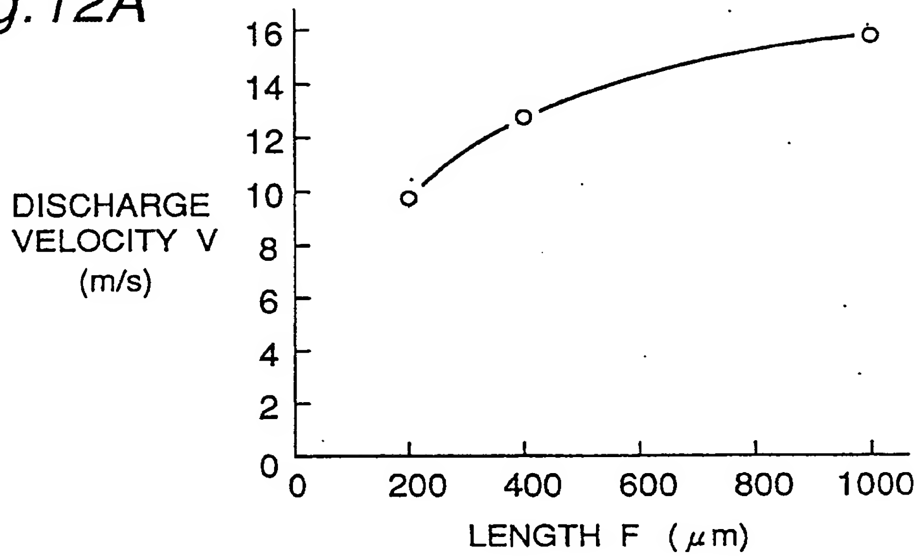


Fig. 12B

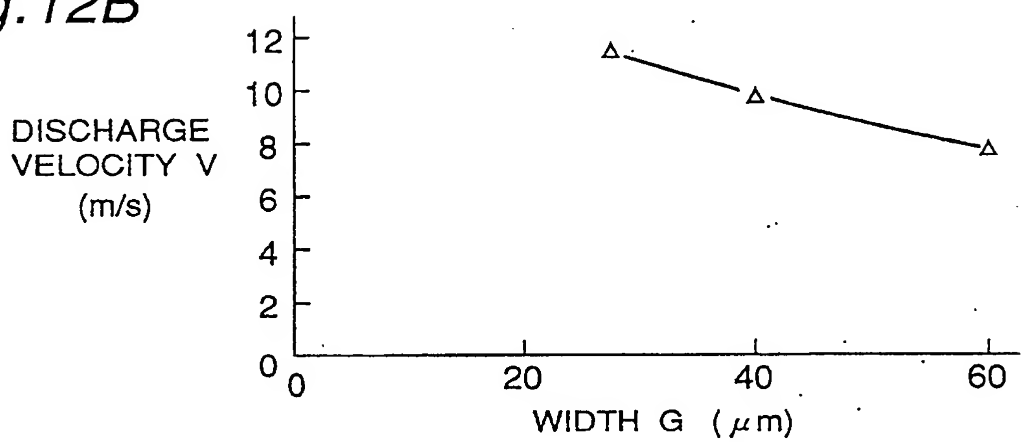


Fig. 12C

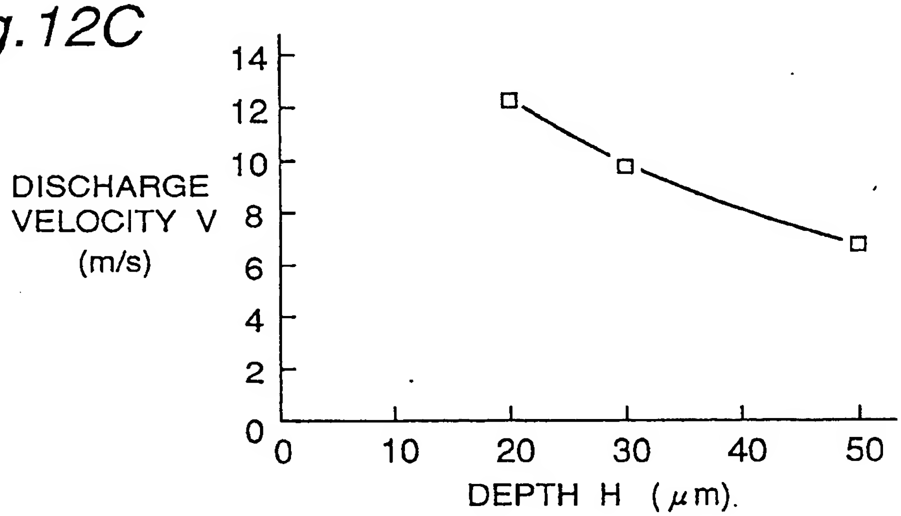


Fig. 13A

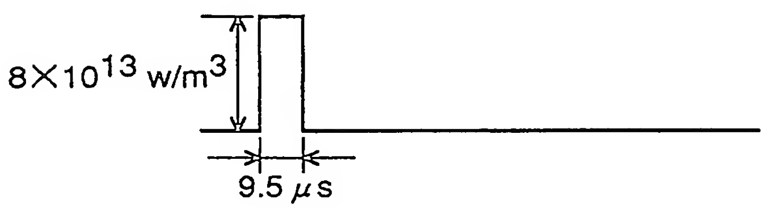


Fig. 13B

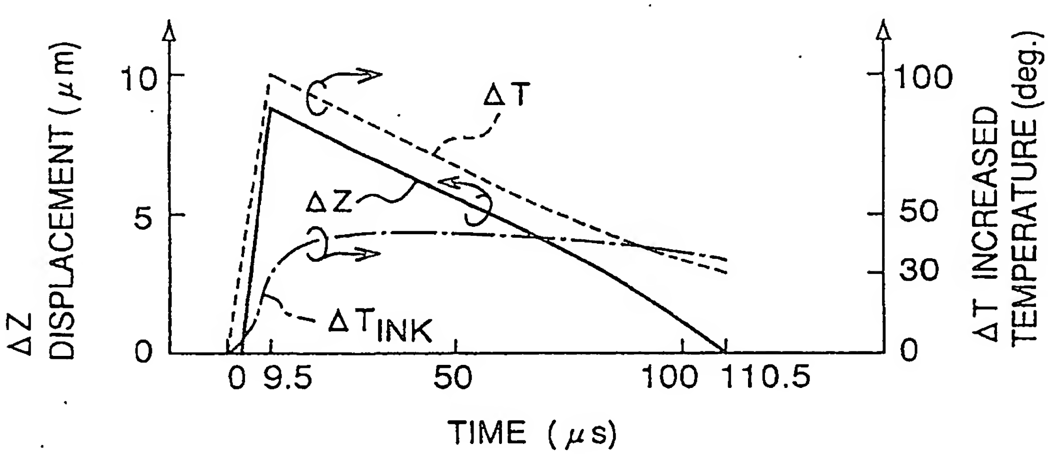


Fig. 14

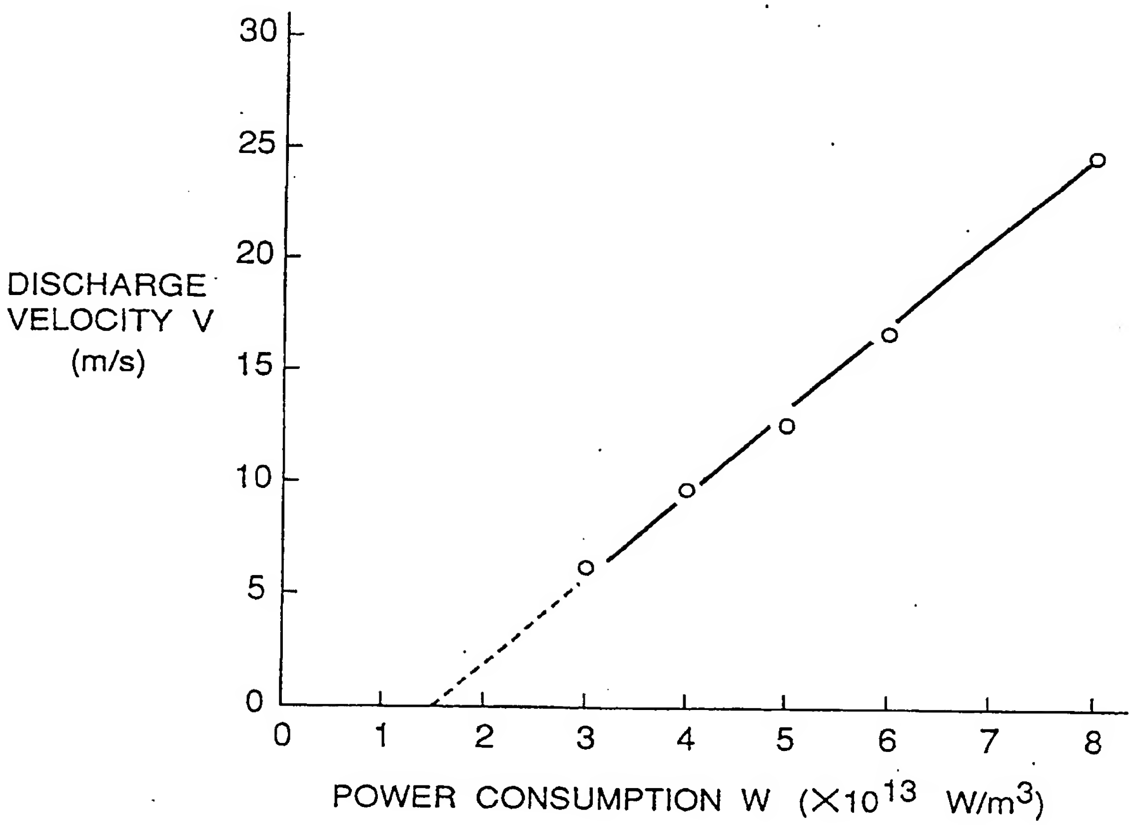

30
25
20
15
10
5
0
DISCHARGE
VELOCITY V
(m/s)
0
1
2
3
4
5
6
7
8
POWER CONSUMPTION W (×10^{13} W/m^3)

Fig. 15A

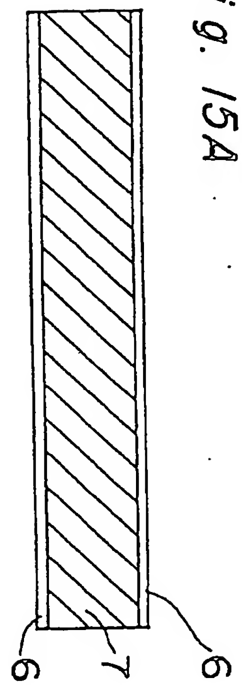


Fig. 16A

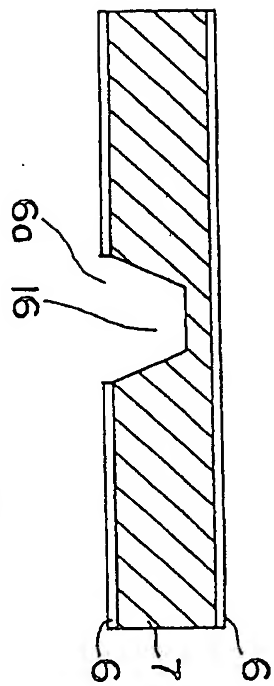


Fig. 17A

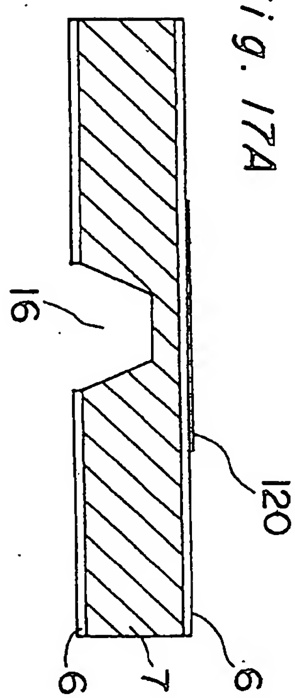


Fig. 15B

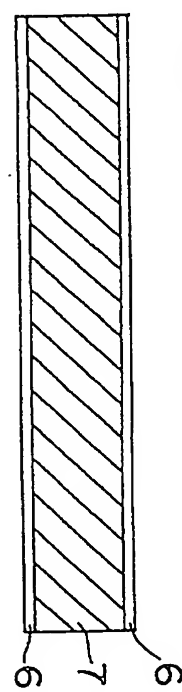


Fig. 16B

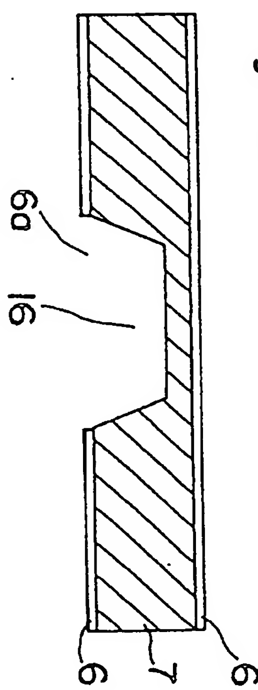


Fig. 17B

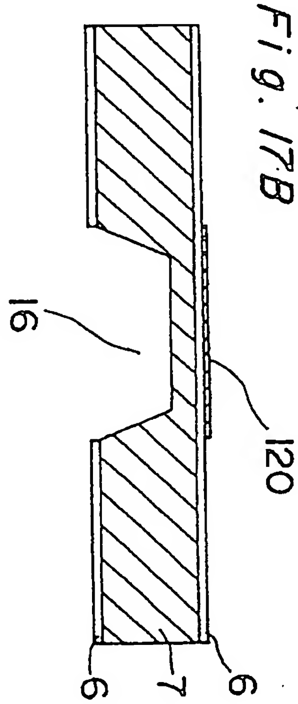


Fig. 18A

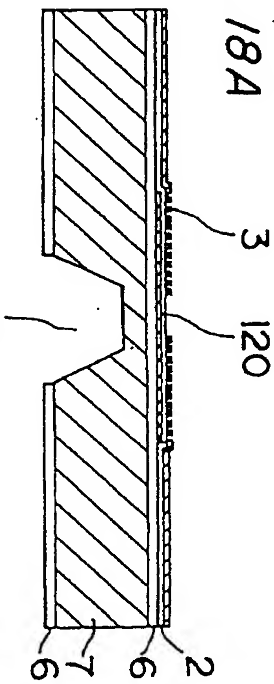


Fig. 18B

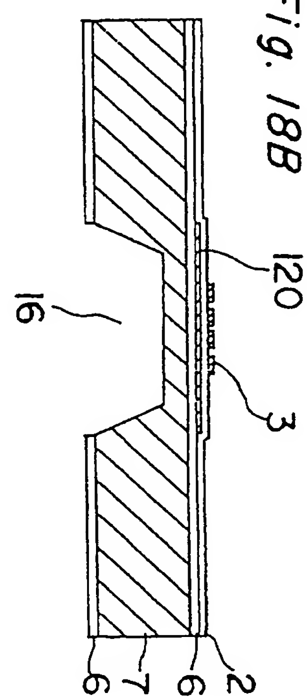


Fig. 19A

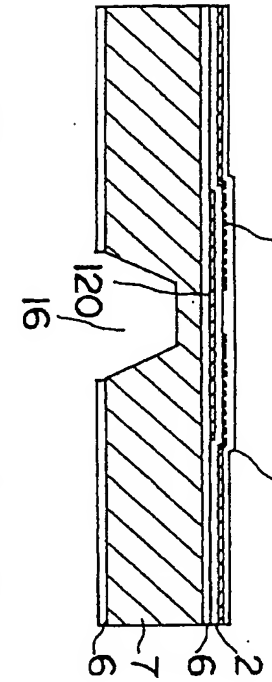


Fig. 19B

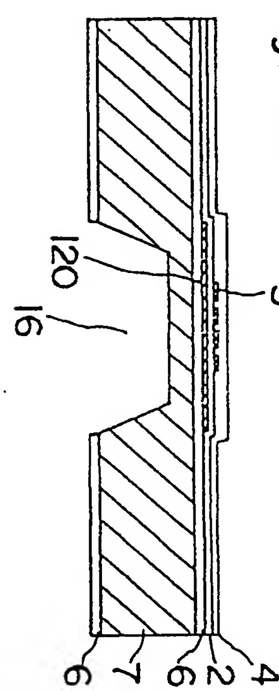


Fig. 20

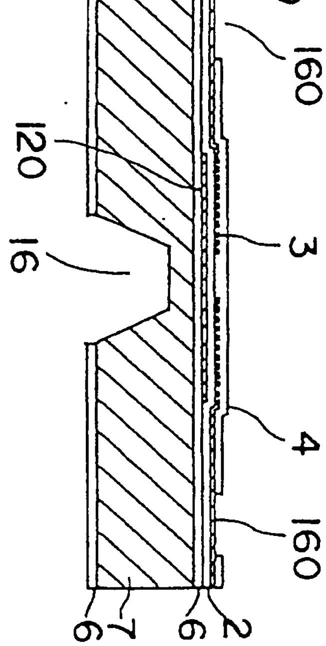


Fig. 21A

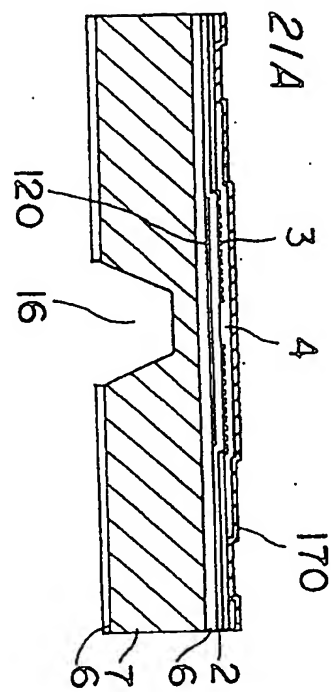


Fig. 21B

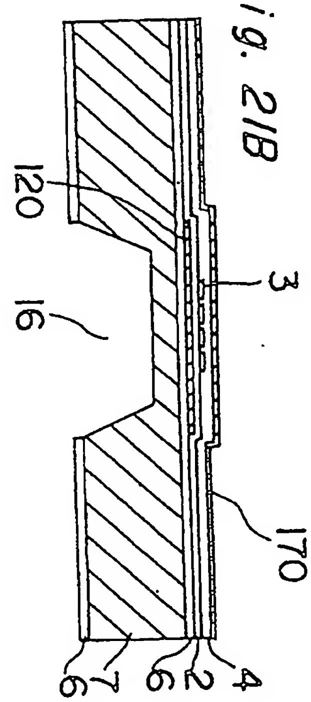


Fig. 22

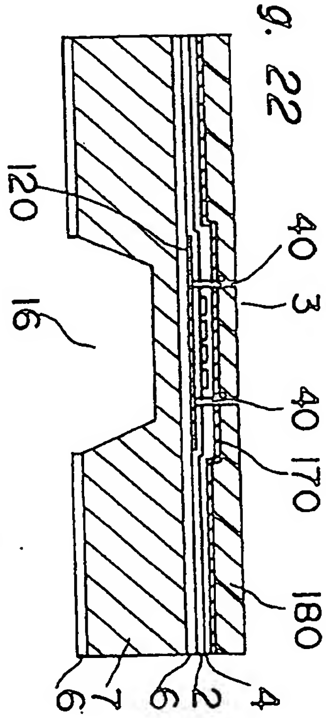


Fig. 23A

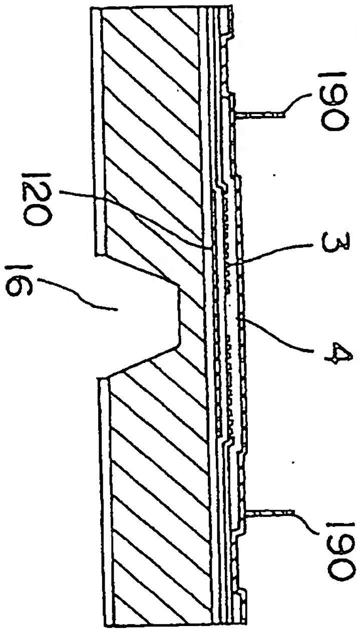


Fig. 23B

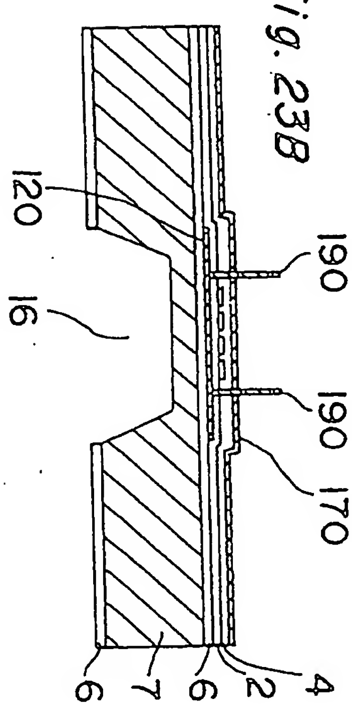


Fig. 24A

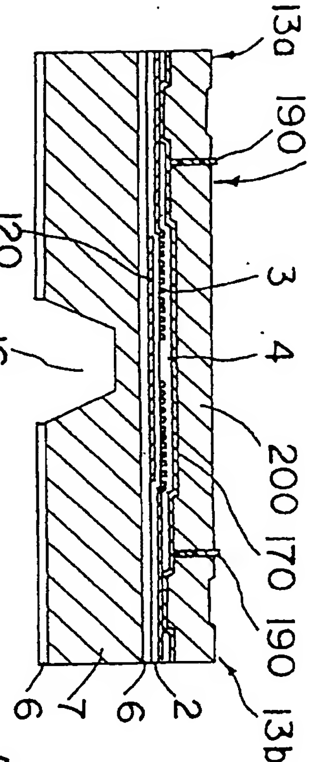


Fig. 25A

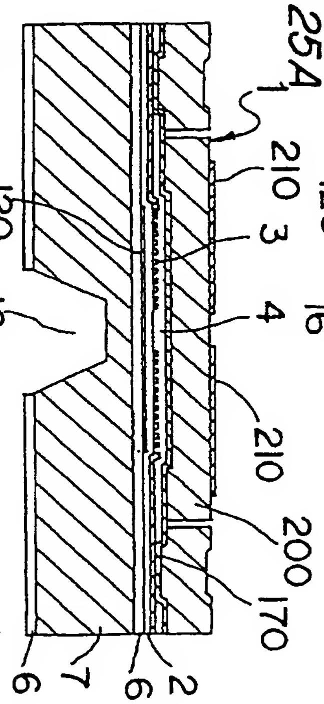


Fig. 26A

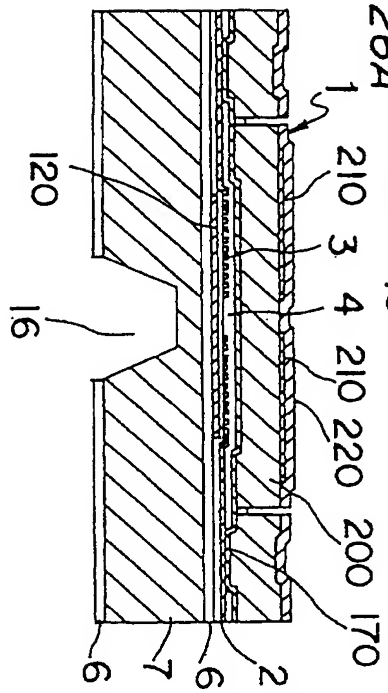


Fig. 24B

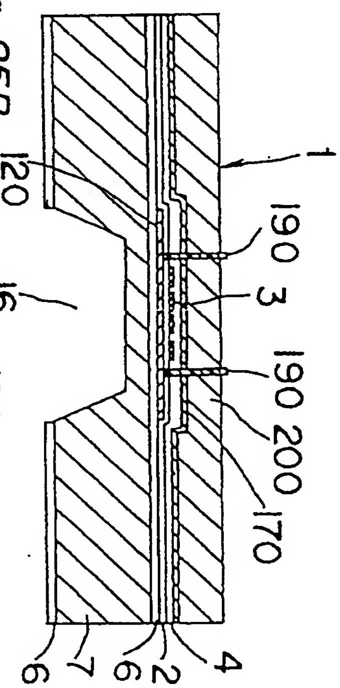


Fig. 25B

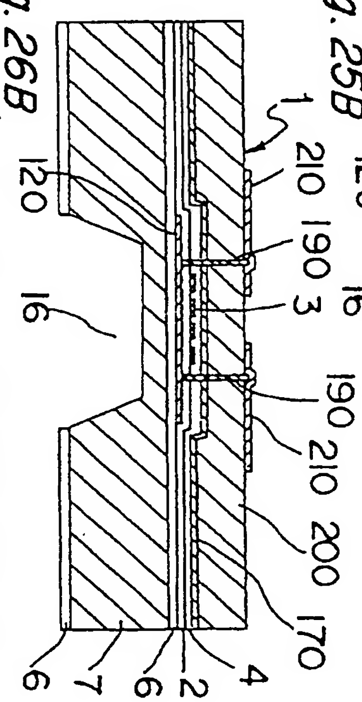


Fig. 26B

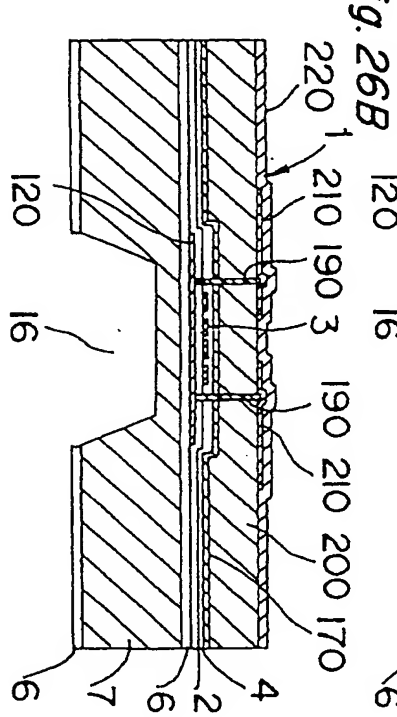


Fig. 27A

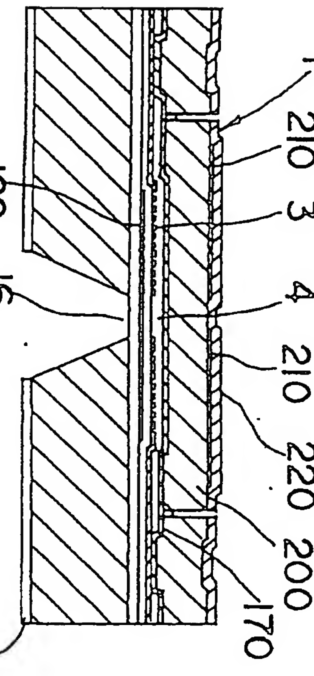


Fig. 28A

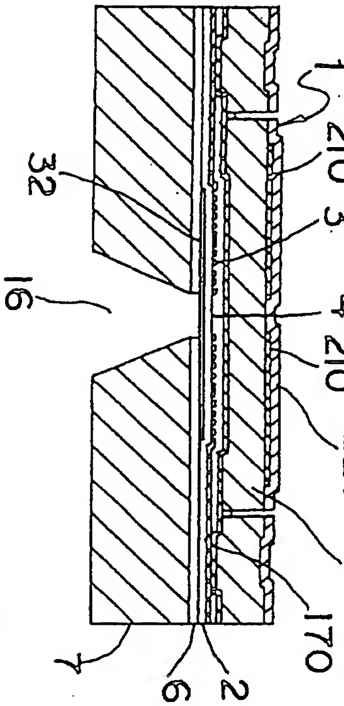


Fig. 27B

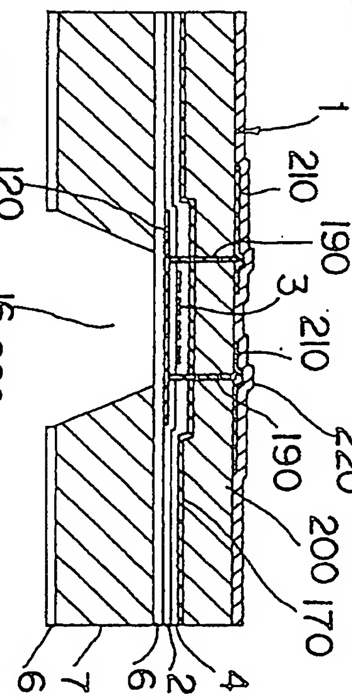


Fig. 28B

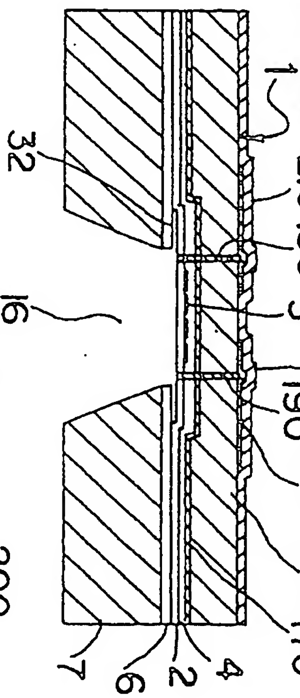
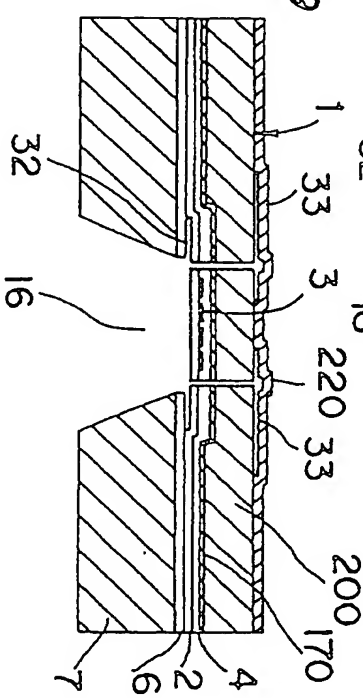


Fig. 29



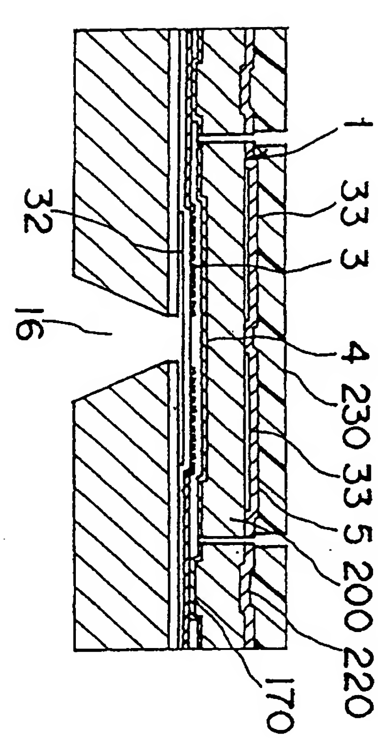


Fig. 30A

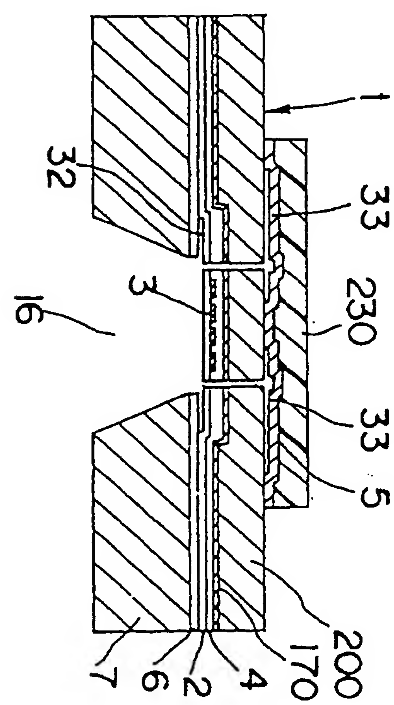


Fig. 30B

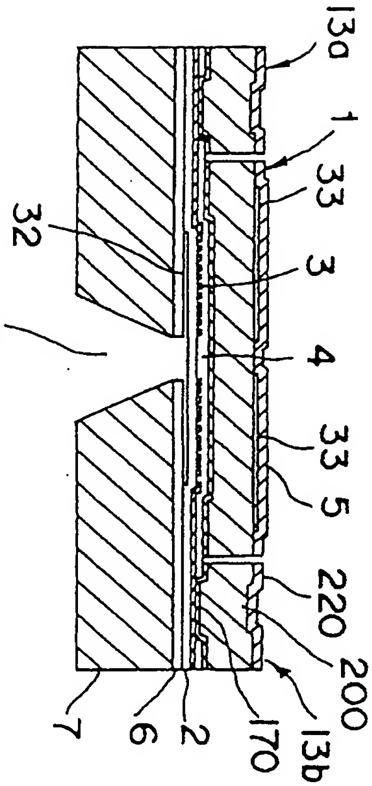


Fig. 31A

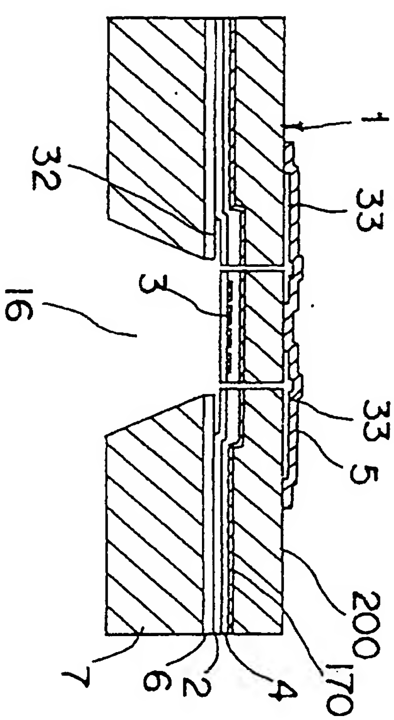


Fig. 31B

Fig 32 PRIOR ART